Determination of Some Properties of Fly Ash with Lime and Cement

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY
IN
MINING ENGINEERING

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CERTIFICATE

This is to certify that the thesis entitled **“Determination of Some Properties of Fly Ash with Lime and Cement”** submitted by **Debakanta Panda and Amit Kumar** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:

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ACKNOWLEDGEMENT

We wish to convey our heartfelt gratitude and obligation to **Prof. M. K. Mishra**, Department of Mining Engineering, and NIT Rourkela for introducing the present topic and for his inspiring guidance, constructive criticism and valuable suggestion throughout the project work.

We are also thankful to **Mr. S. Mallik**, **Mr. S. Oram** and other staffs in Department of Mining Engineering for providing all joyful environments in the laboratory and helping us out in different ways.

Last but not the least our sincere thanks to all our friends who have patiently extended all sorts of help for accomplishing this undertaking.

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ABSTRACT

In India the present generation of fly ash is around 150 million tonnes and utilization percentage is 55-60%. A lot of efforts and innovations are required to achieve 100% utilization. Fly ash in itself has little strength. But it gains strength in presence of additives. This investigation is an attempt to develop fly ash composite materials with lime and cement with respect to enhanced compressive strengths, tensile strengths, and shear parameters so as to evaluate the potential in geotechnical usage. Calcium carrying material as cement and lime were used as additives. Varying proportions of fly ash, lime and cement were mixed to develop the composite materials. Optimum moisture content, maximum dry density, unconfined compressive strength, Brazilian tensile strength, and shear strength parameters were determined at varying curing period. Fly ash with 5% lime was found to exhibit maximum compressive and tensile strength.

Key Words: Fly ash, lime, cement, curing period, strength

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Chapter 1

INTRODUCTION

BACKGROUND

OBJECTIVES

1.1 INTRODUCTION AND BACKGROUND OF PROBLEM

The combustion of pulverized coal at high temperatures and pressures in power stations produces different types of ash. The 'fine' ash fraction is carried upwards with the flue gases and captured before reaching the atmosphere by highly efficient electro static precipitators. This material is known as **Pulverized Fuel Ash** (PFA) or 'fly ash'. It is composed mainly of extremely fine, glassy spheres and looks similar to cement. The 'coarse' ash fraction falls into the grates below the boilers, where it is mixed with water and pumped to lagoons. This material, known as **Furnace Bottom Ash** (FBA) has a gritty, sand-like texture. Fly ash is one of the residues generated in the combustion of coal. It is mostly captured from the chimneys of coal power plants. The components of fly ash composed vary appreciably, depending upon the source and makeup of the coal being burned. But all fly ash includes bounteous amounts of silicon dioxide (SiO_2) and calcium oxide (CaO). Fly ash is a fine, glass powder recovered from the gasses of blazing coal throughout the processing of power. These micron-sized earth components comprise fundamentally of silica, alumina and iron. The distinction between fly ash and Portland cement gets illusive under a magnifying instrument. Fly ash particles are just about completely round fit as a fiddle, permitting them to stream and mix uninhibitedly in mixtures.

Thermal power generation is around 73% of the nation's aggregate power generation, of which coal-based is 90%. Around 85 thermal power stations, furthermore a few captive power plants use bituminous and sub-bituminous coal and supply plentiful amounts of fly ash. High ash content (30% - half) coal reinforce to these expansive volumes of fly ash. Ash generation of the thermal power plants has expanded from something like 40 million tons throughout 1993-1994 to 120 million tons throughout 2005-06 and 175 million tons for every year by 2012, because of the proposal to two fold the power generation. More than 120 million tons of coal ash are shot out from power plants in India. Very nearly 40% is the usage rate, and the rest is discarded ashore. 70% of aggregate use is secured in the cement business, in which a huge build in use is not expected later on due to points of confinement to worthy amount. This investigation is an attempt to develop a material with potential for large usage.

1.2 OBJECTIVES

The objective of this study is to develop a fly ash composite material with sufficient strength attributes for geotechnical application. This requires following specific objectives:

- ✓ Investigation into the engineering properties and characteristics of the fly ash samples collected.
- ✓ Establishment of better suited combinations of fly ash- lime- cement compositions for compressive strength test, tensile test, shear teat under laboratory scale/conditions.
- ✓ Establishment of better suited combinations of fly ash- Cement- cement compositions for compressive strength test, tensile test, shear teat under laboratory scale/conditions.

1.3 EXPERIMENTAL STUDY PLAN

In order to achieve the objectives outlined, the study plan is divided into the following stages.

- **Collection of the fly ash samples:** samples were collected from a Rourkela steel unit with captive thermal power plant.
- **Collection of data:** for the fulfillment of the objectives mentioned above & to carry out proper investigation into the strength characteristics of fly ash, various necessary data & literatures were collected from different books, journals & internet.
- **Preparation of the samples to be tested:** samples of different size were prepared taking Fly Ash, Fly Ash & Cement, Fly Ash & Lime
- **Tests to be performed:** For the samples collected, various strength experiments e.g. UCS, UTS, & Shear test was carried out in the laboratory.
- **Results & discussions:** Characterization of the fly ash samples with respect to the engineering properties of composite material based on the results.

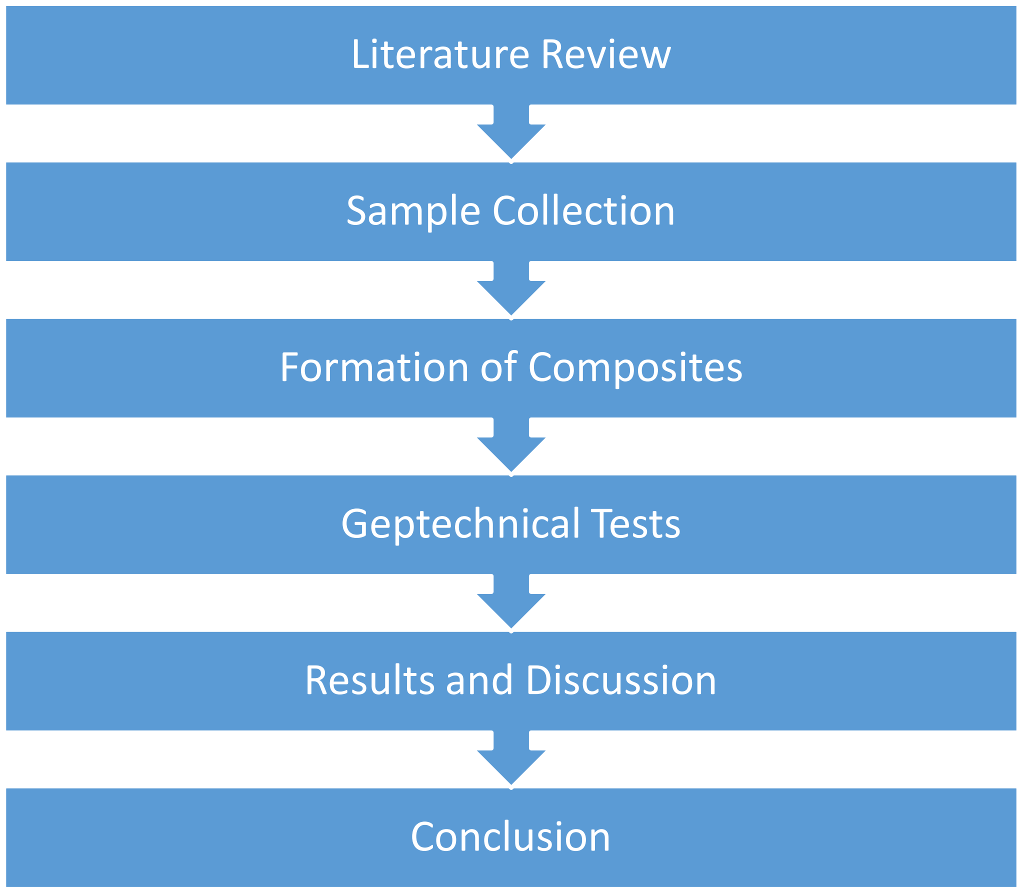

Fig. 1.1 Flow chart of the project investigation

Chapter 2

LITERATURE REVIEW

GENERATION

TRANSPORTATION

CHARACTERISTICS OF FLYASH

UTILIZATION

2.1 FLY ASH GENERATION

The fly ash generated from burning of pulverized coal in a coal-fired boiler is a fine grained, powdery particulate material that is carried off in the flue collected from the flue gas by using electrostatic precipitators, baghouses, or mechanical collection devices such as cyclones. There are three types of coal-fired boiler furnaces used in the electric utility industry. They are named as dry-bottom boilers, wet-bottom boilers, and cyclone furnaces. The most used is the dry-bottom furnace.

Something like 80 percent of all the ash leaves the furnace as fly ash when pulverized coal is combusted in a dry-ash, dry-bottom evaporator. Essentially About 50 percent of all the ash leaves the furnace as fly ash when pulverized coal is combusted in a wet-bottom (or slag-tap) furnace. Where as in a cyclone furnace 70 to 80 percent of the ash is held as kettle slag and just 20 to 30 percent leaves the furnace as dry ash in the pipe gas. A general stream chart of fly ash generation in a dry-base coal-terminated utility evaporator operation is exhibited in the accompanying Figure.

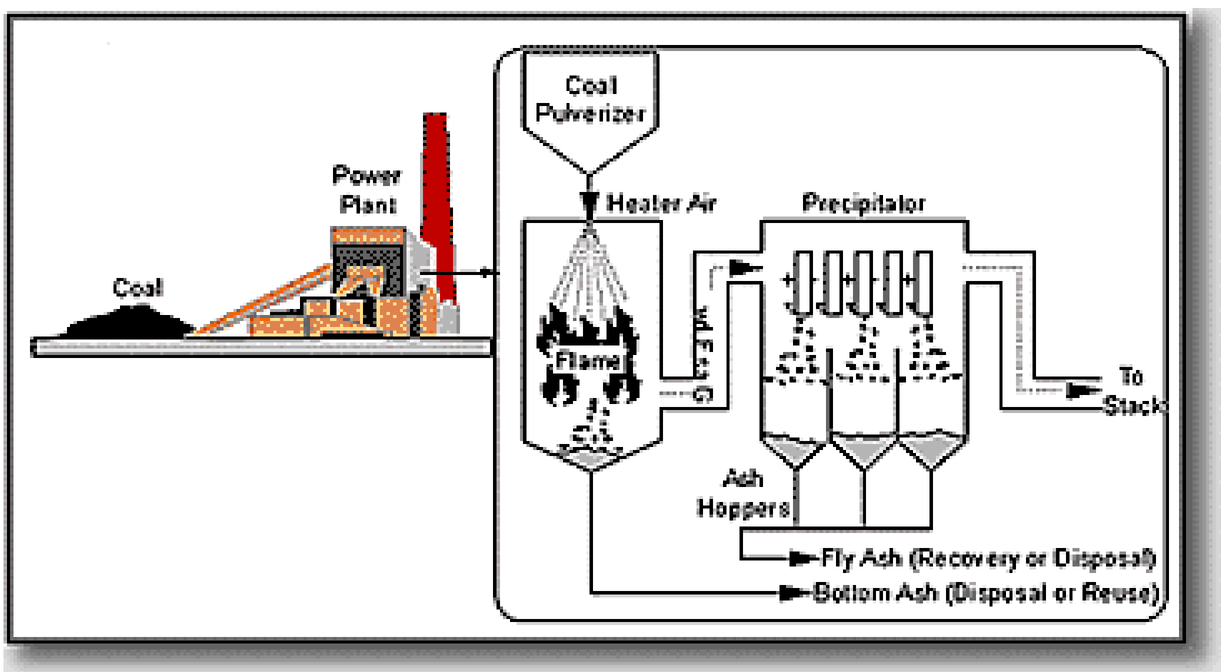

Figure 2.1: Generation of ash at the power plants

(Ref - http://www.fhwa.dot.gov

/publications/research/infrastructure/structures/97148/cfa51.cfm)

2.2 TRANSPORTATION

Fly ash can be supplied in four forms

Dry: This is currently the most used method of supplying fly ash. Dry fly ash is handled in a similar manner to that of Portland cement. It is stored in sealed silos with the associated filtration and desiccation equipment or in bags.

Conditioned: Here water is added to the fly ash to improve compaction and handling. The amount of water added is determined by the end use of the fly ash. Conditioned fly ash is mostly used in aerated concrete blocks grout and specialist fill applications.

Stockpiled: Conditioned fly ash which is not sold immediately is stockpiled and can be used at a later date. The moisture content of stockpiled ash is generally 10 to 15 %. Uses of this ash are mostly in large fill and bulk grouting applications.

Lagoon: Some of the power stations pump fly ash as slurry to large lagoons. Before the moisture content of deposited fly ash has reached a safe level these are drained and may be recovered later. The moisture content can vary from around 5 % to over 30 %.

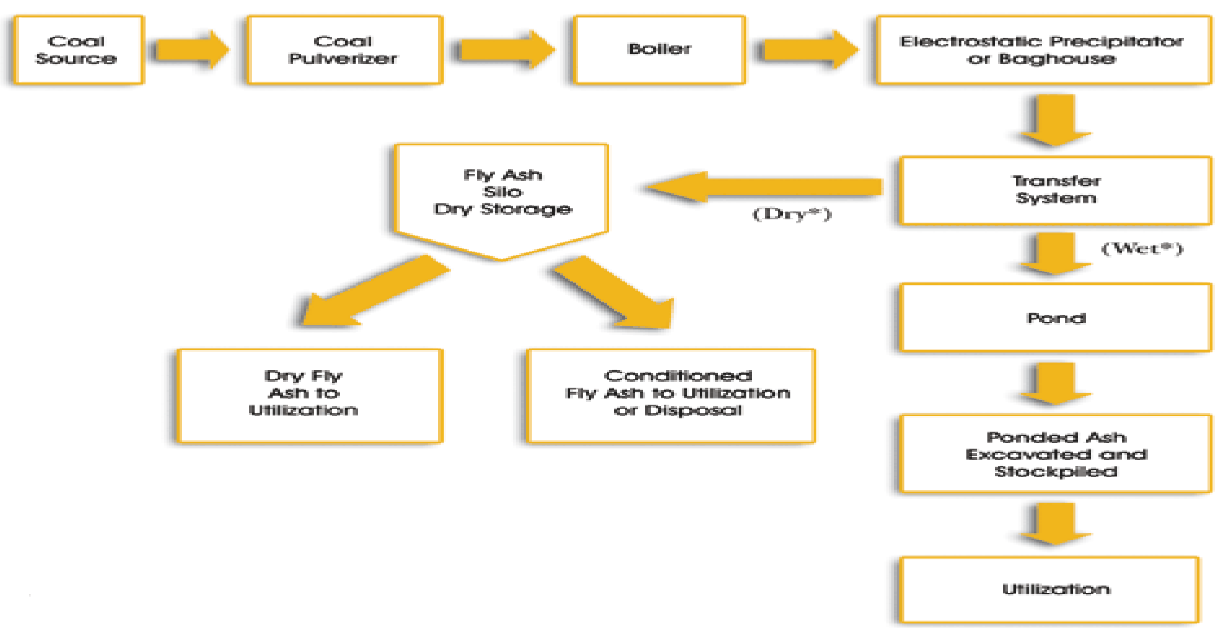

Figure 2.2: Method of fly ash transfer can be dry, wet or both

(Ref - http://www.fhwa.dot.gov/pavement/recycling/fach01.cfm)

2.3 CHARACTERIZATION OF FLY ASH

The high ash content (30–50%) of the coal in India creates problems of handling and disposal of the ash produced. Now about 85 thermal power stations produce nearly 110 million tonnes of coal ash per annum. Safe disposal of the ash without affecting the environment and the area required for large storage are main concerns. Hence attempts are done to utilize the ash rather than to dump it. It can be utilized in a major amount only in geotechnical engineering applications such as construction of embankments, as a backfill material, as a sub-base material, etc. So characterization of the fly ash with reference to geotechnical applications is required.

2.3.1 Physical properties

It helps in classifying the coal ashes for engineering purposes. The properties are specific gravity, grain size distribution, index properties, free swell index and specific surface.

2.3.1.1 Specific gravity

It is one of the important physical properties required for the use of coal ashes for geotechnical and other applications. The specific gravity of coal ashes ranges around 2.0 but can vary to a range of 1.6 to 3.1. Low value of the specific gravity of coal ash compared to soils, results low dry densities. The lesser unit weight is of advantage in using it as a backfill material for retaining walls.

2.3.1.2 Grain size distribution

It indicates if a material is well graded, poorly graded, fine or coarse. The Coal ashes are generally silt sized with some sand-size fraction. The studies carried out on Indian coal ashes shows that the fly ashes consist generally of silt-size fraction with some clay-size fraction. The pond ashes consist of silt-size fraction with some sand-size fraction. The bottom ashes are coarser particles. Based on the grain-size distribution, the coal ashes can be classified as sandy silt to silty sand.

2.3.1.3 Index properties

These are extensively used in geotechnical engineering practice. Among all the properties liquid limit is an important physical property for use in classification and for correlations with engineering properties. Now a days two methods (Percussion cup and fall cone methods) are popular for the determination of liquid limit of fine-grained soils.

2.3.1.4 Free swell index

It serves as a tool to identify swelling soils in soil engineering. Sridharan et al. modified the definition of free swell index itself to take care of the limitations found in the earlier studies. Experiments were carried out at IISc to study the free swell index of coal ashes. The results conclude that 70% of the coal ashes show negative free swell index which is due to flocculation.

2.3.2 Chemical properties

The chemical properties of the coal ashes vitaly influence the environmental impacts that may arise out of their use or disposal and their engineering properties. The worst impacts include contamination of surface and subsurface water with toxic heavy metals present in the coal ashes, loss of soil fertility around the plant sites. Therefor this calls for a detailed study of their chemical composition, morphological studies, pH, total soluble solids, etc.

2.3.2.1 Chemical composition

Chemical composition commits the possible applications for coal ash. The study carried out on Indian fly ashes show that all the fly ashes contain silica, alumina, iron oxide and a bit calcium oxide. The silica content in fly ashes is between 38 and 63%, and 27 and 73% in bottom ashes, 37 and 75% in pond ashes. The alumina content ranges between 27 and 44% for fly ashes, 11 and 53% for pond ashes and 13 and 27% for bottom ashes. The calcium oxide is in the range of 0 to 8% for fly ashes, 0.2 to 0.6% for pond ashes and 0 to 0.8% for bottom ashes.

2.3.2.2 X-ray diffraction

X-ray diffraction studies are carried out mainly to identify the mineral phases. The studies carried out reflect that coal ashes predominantly consist of quartz and feldspar minerals. The studies carried out at IISc reveal that the major mineral in coal ashes is quartz with lesser proportions of feldspars, carbonates and chlorites. The range of chemical composition of Indian coal ashes together with that for soil (for comparison purposes) is reported in Table .2.1.

Table 2.1: Range of chemical composition of Indian Coal Ashes

Compounds	Fly ash	Pond ash	Bottom ash	Soils
SiO_2	38-63	37.7-75.1	23-73	43-61
Al_2O_3	27-44	11.7-53.3	13-26.7	12-39
TiO_2	0.4-1.8	0.2-1.4	0.2-1.8	0.2-2
Fe_2O_3	3.3-6.4	3.5-34.6	4-10.9	1-14
MnO	0-0.5	bd-0.6	bd-0.3	0-0.1
MgO	0.01-0.5	0.1-0.8	0.1-0.7	0.2-3.0
CaO	0.2-8	0.2-0.6	0.1-0.8	0-7
Na_2O	0.07-0.43	0.05-0.31	bd-0.3	0.2-3
LOI	0.2-3.4	0.01-20.9	0.61-51.6	5-16

2.3.2.3 pH

Generally, fly ash can be classified as an amorphous ferro-alumino silicate mineral. The amorphous iron aluminum oxides as well as manganese oxides present on the surface of fly ash particles act as a sink, adsorbing the trace elements. The extent of solubility of these oxide sinks determines the release of the elements associated with them into the aqueous medium.

2.3.2.4 Total soluble solids

The presence of soluble solids is a vital aspect requiring examination since the water soluble solids highly influence the engineering properties. Further, the solubility of nutrient elements such as calcium, magnesium, iron, sulphur, potassium and manganese affect the crop yield to a great extent.The present investigations showed that the soluble solids range between 400-17600 ppm for fly ashes, 800-3600 ppm for pond ashes, and 1400-4100 ppm for bottom ashes.

2.3.2.5 Lime reactivity

The strength of fly ash usually improves with time due to pozzolanic reactions. Reactive silica and free lime contents are recommended for pozzolanic reactions to take place. Lime reactivity is a property that depends on the proportion of reactive silica in coal ash. Based on the work at IISc, it is found that a high percentage of free lime in coal ash plays an important role in increasing its lime reactivity.

2.4 ENVIRONMENTAL IMPACTS OF FLY ASH

The World Bank has cautioned India that by 2015, disposal of coal ash would require 1000 sq. km. of land. Since coal currently accounts for 70% of power production in the country, there is a need of new and innovative methods for reducing impacts on the environment. Currently more 100 million tonnes of fly ash are being generated annually in India, with 65000 acres of land being occupied by ash ponds. Such a huge quantity dose poses challenging problems, in the form of land use, health hazards and environmental damages.

- It is a very difficult material to handle in dry state because it is very fine and readily airborne even in mild wind.
- It disturbs the ecology of the region, being a source of soil, air and water pollution.
- Long inhalation of fly ash causes silicosis, fibrosis of lungs, bronchitis, pneumonitis etc.
- Flying fine particles of ash poses problems for people living near power stations, corrode structural surfaces and affect horticulture.

2.5 UTILIZATION OF FLY ASH

The use of fly ash as an engineering material primarily stems from its pozzolanic nature, spherical shape, and relative uniformity. Fly ash recycling, in descending frequency, includes usage in:

- Portland cement and grout
- Embankments and structural fill
- Waste stabilization and solidification
- Raw feed for cement clinkers
- Mine reclamation
- Stabilization of soft soils
- Road sub base
- Aggregate
- Flow able fill
- Mineral filler in asphaltic concrete
- Other applications include cellular concrete, geopolymer, roofing tiles, paints, metal castings, and filler in wood and plastic product.

Chapter 3

MATERIALS AND METHODS

PROCTOR HAMMER TEST

PREPARATION OF FLY ASH COMPOSITE MATERIAL

UNIAXIAL COMPRESSION TEST

BRAZILLIAN TEST

DIRECT SHEAR TEST

3.1. SAMPLE COLLECTION

The fly ash was gathered from the close-by power plant Local Steel Plant. The plant is arranged close to the two significant coalfields. It devours 2230 ton of coal for every year and transforms about 600 ton of fly ash for every year. The fly ash is normally dumped in adjacent lake range. The fly ash utilized as a part of the present study was gathered in dry state from electrostatic precipitators of the plant. Each pack was fixed quickly after fly ash accumulation. The sacks were then transported with forethought from the plant to lab and kept in the laboratory.

3.2 PROCTOR HAMMER TEST FOR OPTIMUM MOISTURE COMTENT OF THE COMPOSITES

3.2.1 Objective

To determine the optimum moisture content (OMC) of the composite.

3.2.2 Apparatus Required

1. Proctor mould having a capacity of 999 cc.
2. Sample extruder.
3. A balance of 15 kg capacity.
4. Sensitive balance.
5. Straight edge.
6. Graduated cylinder.
7. Mixing tools.
8. Moisture tins.

3.2.3 Procedure

1. An oven-dried sample, approximately 5 kg was taken in the pan. It was thoroughly mixed with sufficient water not greater than optimum moisture content.
2. The weight of proctor mould without base plate and collar was taken.
3. The sample was placed in the Proctor mould and compacted in 3 layers giving 25 blows per layer.

4. The collar was removed, the sample was trimmed even with the top of the mould by a straight edge and the weight was taken.
5. The sample was removed from the mould and sliced vertically through to obtain a small sample for moisture determination.
6. Water was added in sufficient amounts to increase the moisture content of the soil sample by one or two percentage points.
7. The above procedure was repeated for each increment of water added.
8. This series of determination was continued until there was a decrease in the wet unit weight of the compacted soil.

3.2.4 Calculation

Wet density (gm/cc) = weight of compacted soil / Vol. of mould

Moisture content (%) = weight of water x 100 / Weight of dry soil

Dry density (gm/cm) = Wet density / (1+0.01 x M.C.)

The dry density was plotted against moisture content the optimum moisture content was found out for the composite.

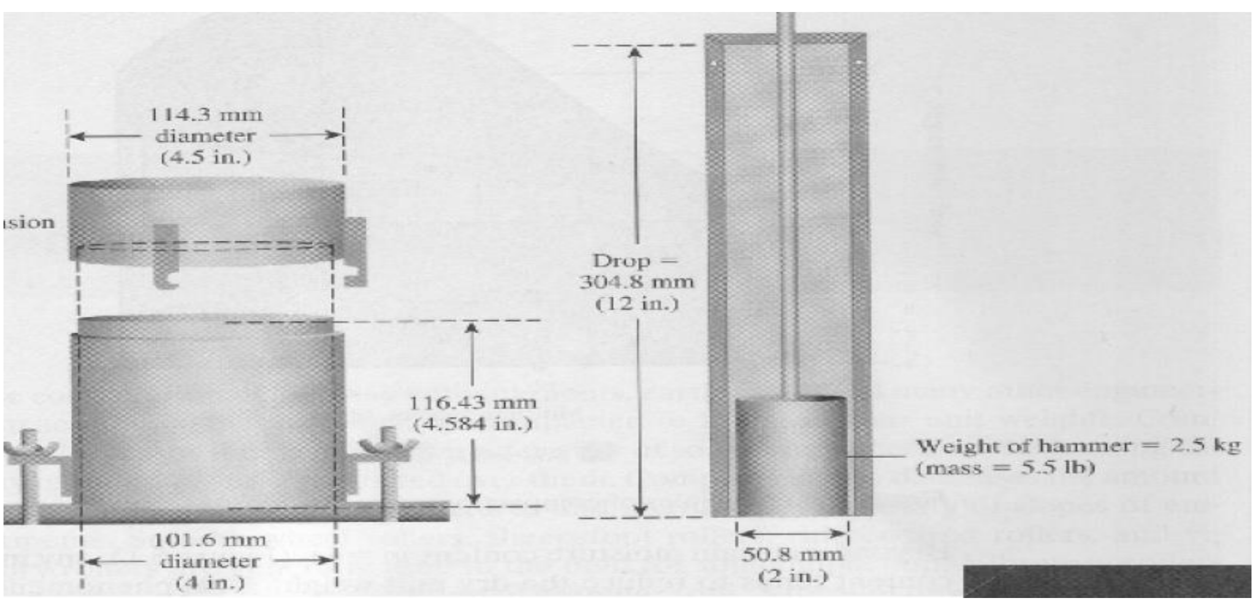

Figure 3.1 Sketch of a Proctor Hammer Apparatus

(Ref - www.engr.uconn.edu/~lanbo/CE240LectW033Compaction.pdf)

3.3. PREPARATION OF FLY ASH COMPOSITE MATERIAL

The fly ash from the local power plant was taken for preparation of composites. On the basis of the literature review, different lime & cement proportions (0, 3, and 5) % of fly ash (by weight) was taken.

3.3.1 Materials Required:

1. Fly ash about 30 Kg
2. Lime about 2 Kg
3. Cement about 2 Kg
4. Digital weight Balance
5. Measuring Cylinder
6. PVC pipes of desired Length

3.3.2 Steps in Preparation

1. Fly ash about 500 gms was taken and required amount of cement (3%, 5%) and lime (3%, 5% of weight of sample) and water quantity (not more than optimum moisture content of the composite) of weight of sample are thoroughly mixed by hand.

2. Then the composite was put inside the pipe in a transparent sheet. Adequate ramming was done with a rod for proper compaction.

3. Then it was kept inside a plastic mould for 24 hour.

4. The samples were cast to size of. 56 mm diameter and 140 mm length for compressive strength tests and 28 mm length and 56 mm diameter for tensile strength test.

5. The samples were taken out of mould and placed inside humidity control chambers for curing where the temperature was maintained at about 25°C and humidity 90%.

The following mixes were used in the investigation:

1. 100 FA+ 0 C + 0 L
2. 97 FA+ 3 C + 0 L
3. 95 FA+ 5 C + 0 L
4. 97 FA+ 0 C + 3 L
5. 95 FA+ 0C + 5 L

FA-Fly ash, C- Cement, L-lime

3.4 UNIAXIAL COMPRESSION TEST:

3.4.1 Purpose: To determine the uniaxial compressive strength of Fly ash composite material

3.4.2 Procedure:

1. The samples of L/D ratio is taken as 2.5:1.

2. The specimen was placed on the base plate of the load frame.

3. A hardened steel ball was placed on the bearing plate.

4. The center line of the specimen was adjusted such that the proving ring and the steel ball were in the same line.

5. A dial gauge was fixed to the base plate to measure vertical compression.

6. The gear position was adjusted on the load frame to give suitable vertical displacement.

7. The load was applied till failure and the readings were taken and the failure load was calculated from the calibration chart.

Fig. 3.2 Uniaxial Compression testing machine

3.5. BRAZILIAN TEST:

3.5.1 Purpose: To evaluate the tensile strength of fly ash composite material.

3.5.2 Procedure:

1. Specimens with L/D ratios of 0.5 were placed in a compression loading machine as shown in fig- .
2. The center line of the specimen was adjusted such that the proving ring and the steel ball were in the same line.
3. A dial gauge was fixed to the base plate to measure the vertical compression.
4. The gear position was adjusted on the load frame to give suitable vertical displacement.
5. The load was applied till failure and the readings were taken and the failure load was calculated from the calibration chart.

3.5.3 Calculation:

Tensile strength = $2P/\pi DT$

Where P = Failure Load

D = Diameter of the sample.

T = Thickness of the sample.

Figure 3.3 Brazilian Test Apparatus

3.6. DIRECT SHEAR TEST

3.6.1 Objective

To determine the cohesive strength and friction angle of the sample, using direct shear apparatus.

3.6.2 Apparatus Required

1. Direct shear box apparatus
2. Loading frame
3. Dial gauge.
4. Proving ring.
5. Tamper.
6. Straight edge.
7. Balance to weigh up to 200 mg.
8. Aluminum container.
9. Spatula.

Figure 3.4 Direct Shear Test Apparatus

3.6.3 Procedure

4. The sample was placed in smooth layers.

6. The surface of the sample was made plane.

7. The upper grating was placed on stone and loading block on top of soil.

9. The desired normal load was applied.

10. The shear pin was removed.

11. The dial gauge was attached which measures the change of volume.

12. The initial reading was taken of the dial gauge and calibration values.

14. The motor was started. The readings of the dial gauge and proving ring was taken at 20mm interval.

15. Readings were taken till failure.

16. 5 kg normal stress or 0.5 kg/cm2 was added and the experiment was continued till failure.

17. The dial gauges were set zero, before starting the Experiment

3.6.4 Calculation

$S=C+ \sigma \tan \Phi$

Where S = shear strength of the sample

C = cohesion of the sample

Φ = Angle of internal friction.

σ = Normal Stress

Chapter 4

RESULTS AND DISCUSSION

4.1 OPTIMUM MOISTURE CONTENT

Proctor hammer test was carried out to find out the optimum moisture content of the composites. First dry density was found out by dividing the weight of the compacted sample with the volume of the mould. Then moisture content was found out by keeping the sample in the oven for 12 hours. Graphs were plotted between moisture content vs. dry density for every composites. The moisture content which gives us the maximum dry density is known as optimum moisture content.

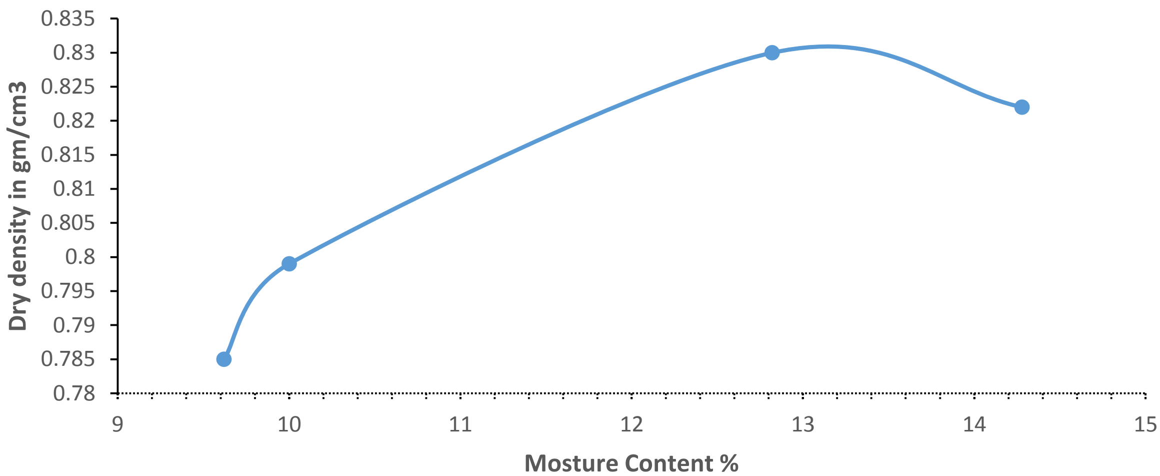

Fig. 4.1 Optimum Moisture Content for Fly ash (100%) + Cement (0%) +Lime (0%)

From the above graph we can conclude that at 13.4% moisture content we are getting maximum dry density 0.83 gm/cm3 and then the value keeps decreasing. So the optimum moisture content for Fly Ash (100 %) sample was found to be 13.4 %.

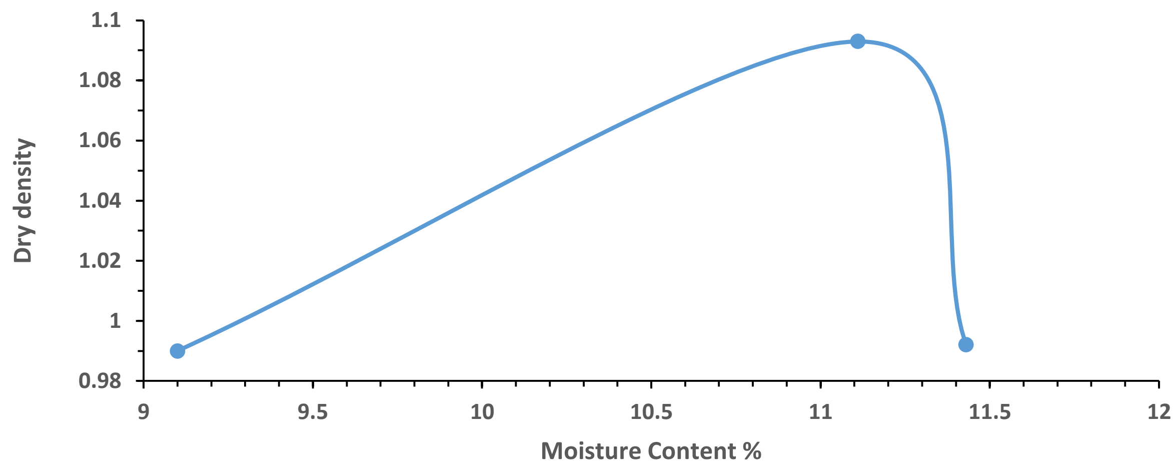

Fig. 4.2 Optimum Moisture Content for Fly ash (97%) + Cement (3%) +Lime (0%)

From the above graph we can conclude that at 11.11% moisture content we are getting maximum dry density 1.09 gm/cm3 and then the value keeps decreasing. So the optimum moisture content for Fly Ash (97 %) + Cement (3 %) sample was found to be 11.11 %.

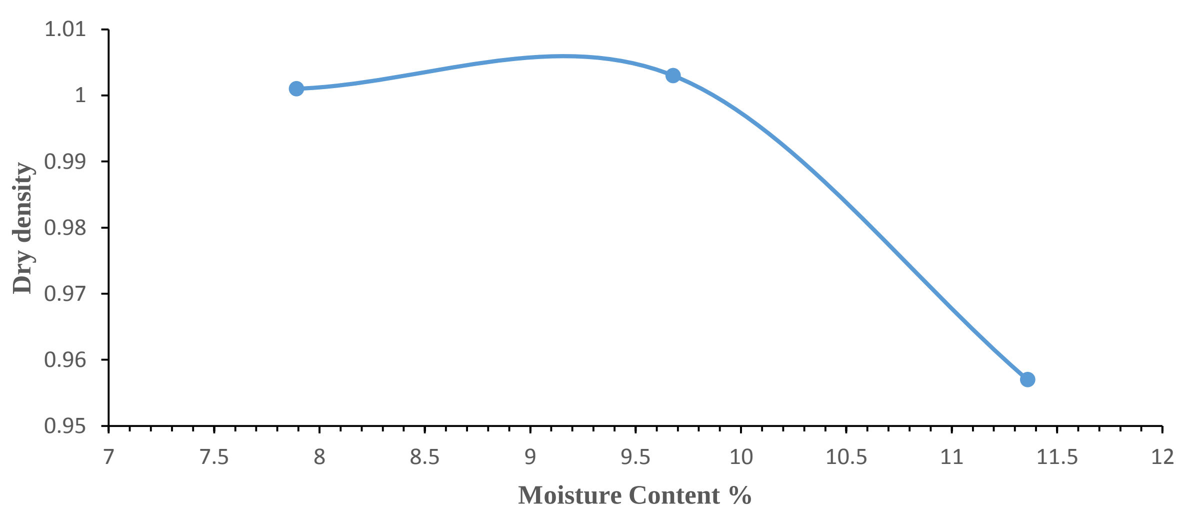

Fig. 4.3 Optimum Moisture Content for Fly ash (95%) + Cement (5%) +Lime (0%)

From the above graph we can conclude that at 9.5% moisture content we are getting maximum dry density 1.005 gm/cm3 and then the value keeps decreasing. So the optimum moisture content for Fly Ash (95 %) + Cement (5 %) sample was found to be 9.5 %.

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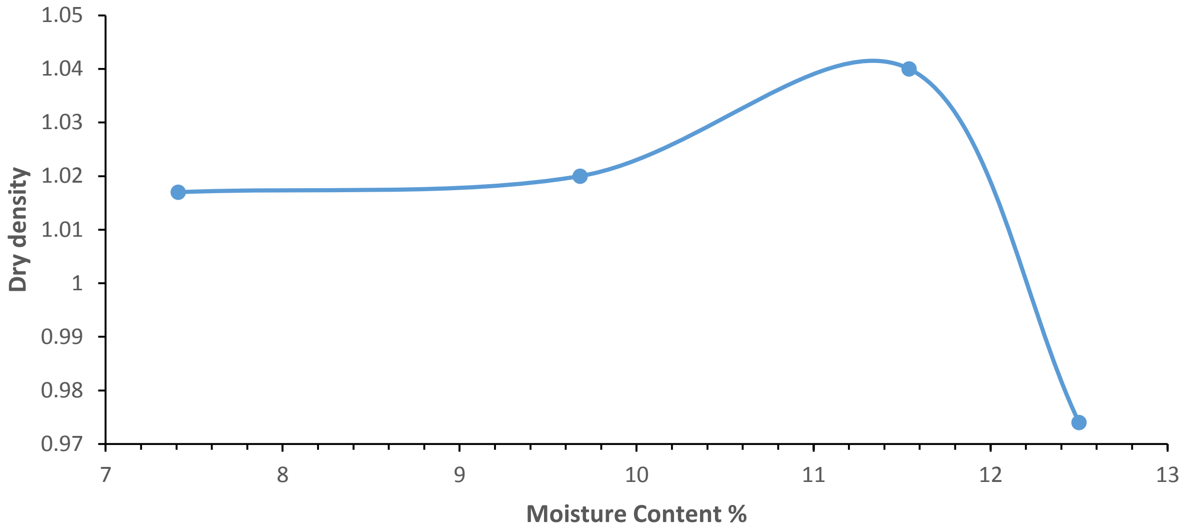

Fig. 4.4 Optimum Moisture Content for Fly ash (97%) + Cement (0%) +Lime (3%)

From the above graph we can conclude that at 11.5% moisture content we are getting maximum dry density 1.04 gm/cm3 and then the value keeps decreasing. So the optimum moisture content for Fly Ash (97 %) + Lime (3 %) sample was found to be 11.5 %.

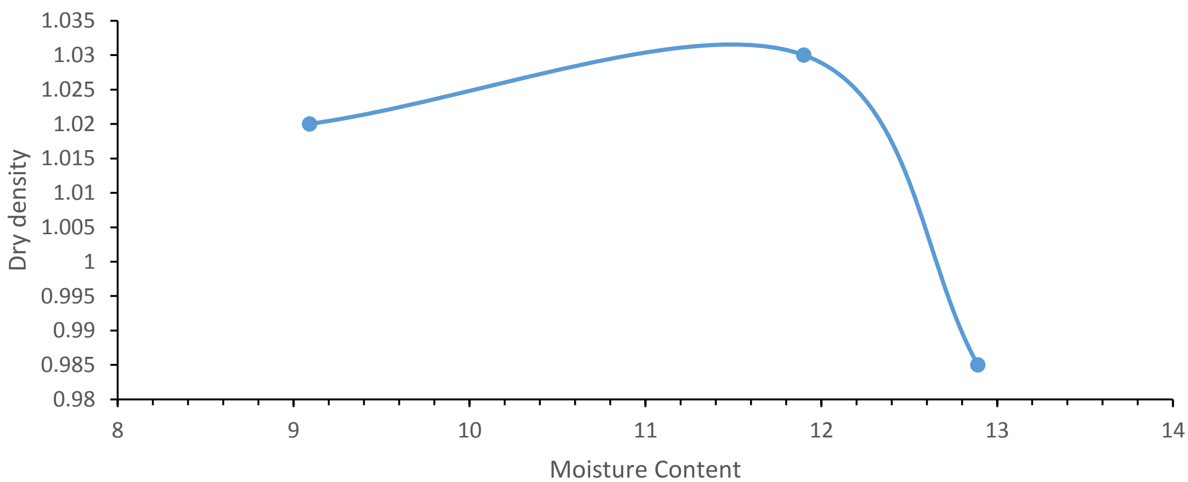

Fig. 4.5 Optimum Moisture Content for Fly ash (95%) + Cement (0%) +Lime (5%)

From the above graph we can conclude that at 11.2% moisture content we are getting maximum dry density 1.03 gm/cm3 and then the value keeps decreasing. So the optimum moisture content for Fly Ash (95 %) + Lime (5 %) sample was found to be 11.2 %.

`

4.2 U.C.S TEST AND BRAZILLIAN TEST

First to find out compressive strength, by U.C.S test and for tensile strength, Brazilian Test were carried out for all the composites. The samples for U.C.S test were of L/D ratio 2.5 and having length of 140mm and diameter 56mm. The samples for Brazilian test were of L/D ratio 0.5 and having length of 28mm and diameter 56mm.These two tests were carried out for all the composites at 7 days, 14 days and 28 days. The results of these tests are given below and the abbreviations used for all the tables are (FA+C+L= Fly Ash in % + C in % + L in %).

4.2.1 at 7 days

Table 4.1 U.C.S and Brazilian Test Results at 7 Days

Combinations	Samples	U.C.S. TEST				BRAZILLIAN TEST			
		Dial gauge reading	Failure Load	U.C.S. in KN/m^2	Avg. U.C.S. in KN/m^2	Dial gauge reading	Failure Load	Tensile Strength in KN/m^2	Avg. Tensile Strength in KN/m^2
FA(100)+ C(0)+ L(0)	**I**	50	0.61	49.53	54.40	12	0.14	11.37	10.55
	II	60	0.73	59.28		10	0.12	9.74	
FA(97)+ C(3)+ L(0)	**I**	150	2.52	204.63	211.53	25	0.29	23.55	25.98
	II	160	2.69	218.43		30	0.35	28.42	
FA(95)+ C(5)+ L(0)	**I**	200	3.36	272.84	286.64	35	0.41	33.29	35.72
	II	220	3.70	300.44		40	0.47	38.16	
FA(97)+ C(0)+ L(3)	**I**	190	3.19	259.03	252.13	35	0.41	33.29	35.72
	II	180	3.02	245.23		40	0.47	38.6	
FA(95)+ C(0)+ L(5)	**I**	290	3.46	280.96	285.425	45	0.53	43.04	40.60
	II	300	3.57	289.89		40	0.47	38.16	

4.2.2 at 14 days

Table 4.2 U.C.S and Brazilian Test Results at 14 Days

Combinations	Samples	U.C.S. TEST				BRAZILLIAN TEST			
		Dial gauge reading	Failure Load	U.C.S. in KN/m^2	Avg. U.C.S. in KN/m^2	Dial gauge reading	Failure Load	Tensile Strength in KN/m^2	Avg. Tensile Strength in KN/m^2
FA(100)+ C(0)+ L(0)	**I**	75	0.91	73.89	76.32	16	0.19	15.43	14.215
	II	80	0.97	78.76		14	0.16	13.00	
FA(97)+ C(3)+ L(0)	**I**	200	3.36	272.84	279.74	40	0.47	38.16	40.60
	II	210	3.53	286.64		45	0.53	43.04	
FA(95)+ C(5)+ L(0)	**I**	340	3.96	321.56	330.895	65	0.76	61.71	59.275
	II	360	4.19	340.23		60	0.70	56.84	
FA(97)+ C(0)+ L(3)	**I**	230	3.86	313.44	320.34	50	0.59	47.90	45.465
	II	240	4.03	327.24		45	0.53	43.03	
FA(95)+ C(0)+ L(5)	**I**	360	4.19	340.23	345.105	75	0.88	71.46	69.02
	II	370	4.31	349.98		70	0.82	66.58	

4.2.3 at 28 days

Table 4.3 U.C.S and Brazilian Test Results at 28 Days

Combinations	Samples	U.C.S. TEST				BRAZILLIAN TEST			
		Dial gauge reading	Failure Load	U.C.S. in KN/m^2	Avg. U.C.S. in KN/m^2	Dial gauge reading	Failure Load	Tensile Strength in KN/m^2	Avg. Tensile Strength in KN/m^2
FA(100)+ C(0)+ L(0)	**I**	85	0.13	83.64	86.075	18	0.21	17.05	16.24
	II	90	1.09	88.51		16	0.19	15.43	
FA(97)+ C(3)+ L(0)	**I**	320	3.77	306.13	311.00	50	0.59	47.91	52.375
	II	330	3.89	315.87		60	0.70	56.84	
FA(95)+ C(5)+ L(0)	**I**	370	4.31	349.98	354.85	70	0.82	66.58	68.995
	II	380	4.43	359.72		75	0.88	71.41	
FA(97)+ C(0)+ L(3)	**I**	370	4.31	349.98	359.725	65	0.76	61.71	59.275
	II	390	4.55	369.97		60	0.70	56.84	
FA(95)+ C(0)+ L(5)	**I**	400	4.64	376.77	381.645	80	0.94	76.33	78.765
	II	410	4.76	386.52		85	1.00	81.20	

4.3 DIRECT SHEAR TEST

Shear Strength Test is carried out to evaluate the material properties as cohesion and angle of internal friction. These parameters reflect the nature of bonding between constituents materials of the sample and reflect its resistance to deformation.

4.3.1 at 7 days

Table 4.4 Direct Shear Test Results at 7 Days

Combinations		Dial Gauge reading	Failure reading	Shear Stress (MPa)	Normal Stress (MPa)	Cohesion (MPa)	Friction Angle
FA(97)+ C(3)+ L(0)	0.5	180	10.3	0.021	0.14	0.0167	$17^{0}34'$
	1.0	160	12.0	0.026	0.28		
	1.5	160	14.0	0.030	0.42		
FA(95)+ C(5)+ L(0)	0.5	40	12.0	0.029	0.14	0.0147	$43^{0}48'$
	1.0	80	15.0	0.038	0.28		
	1.5	40	19.0	0.055	0.42		
FA(97)+ C(0)+ L(3)	0.5	80	10.1	0.026	0.14	0.0157	$35^{0}48'$
	1.0	100	14.2	0.035	0.28		
	1.5	80	18.3	0.046	0.42		
FA(95)+ C(0)+ L(5)	0.5	60	14.2	0.038	0.14	0.0323	$24^{0}00'$
	1.0	120	20.0	0.047	0.28		
	1.5	240	28.0	0.051	0.42		

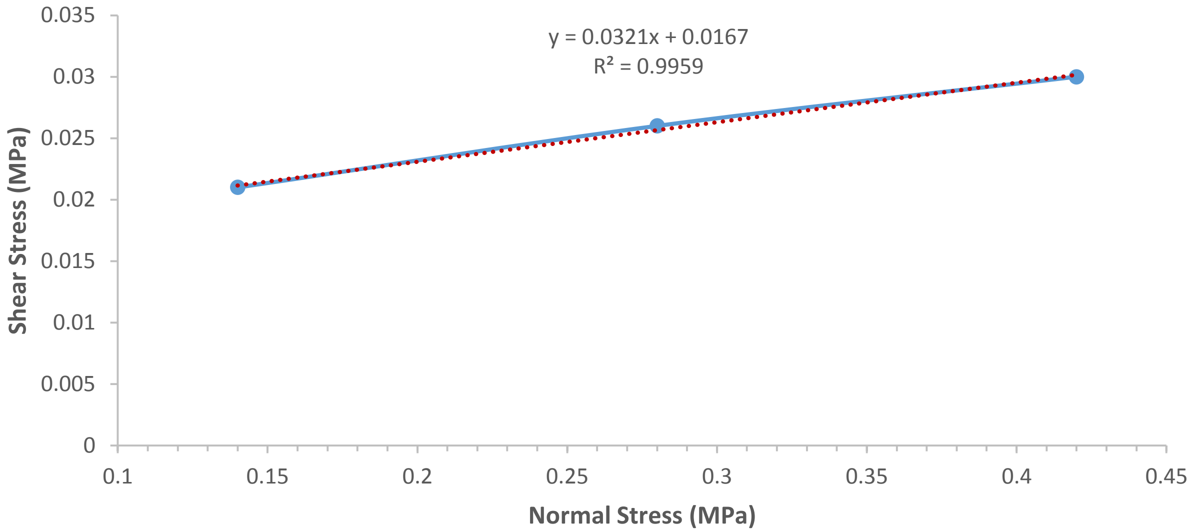

Figure 4.6 Shear Stress vs. Normal Stress for Fly Ash 97% + Cement 3% at 7 Days

From the above graph the X-intercept of the graph was found to be 0.0167, so the cohesive strength is 0.0167 Mpa. The slope of the graph was found to be 0.0321 which on further calculation gives friction angle $17^{0}34'$.

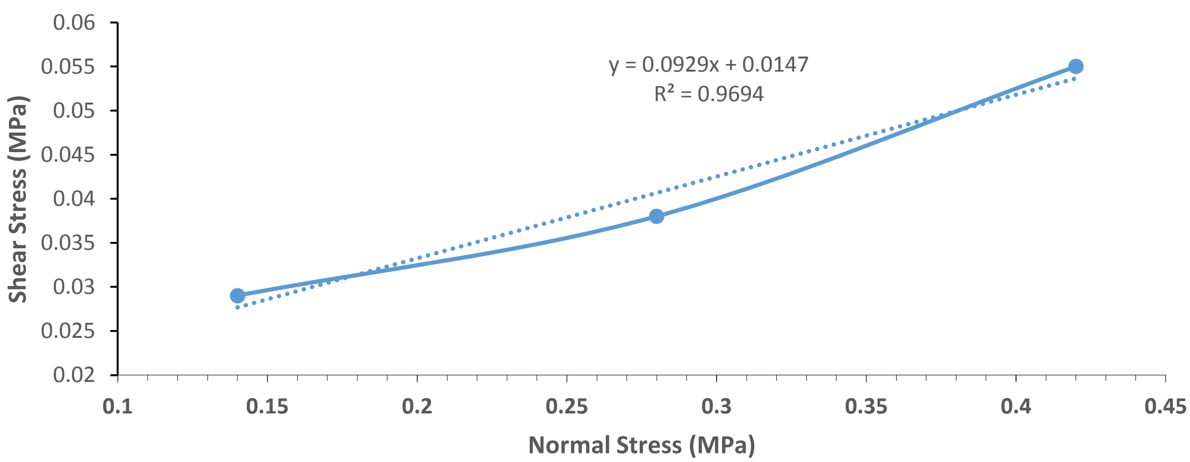

Figure 4.7 Shear Stress vs. Normal Stress for Fly Ash 97% + Cement 5% at 7 Days

From the above graph the X-intercept of the graph was found to be 0.0147, so the cohesive strength is 0.0147 Mpa. The slope of the graph was found to be 0.0929 which on further calculation gives friction angle $43^{0}48'$.

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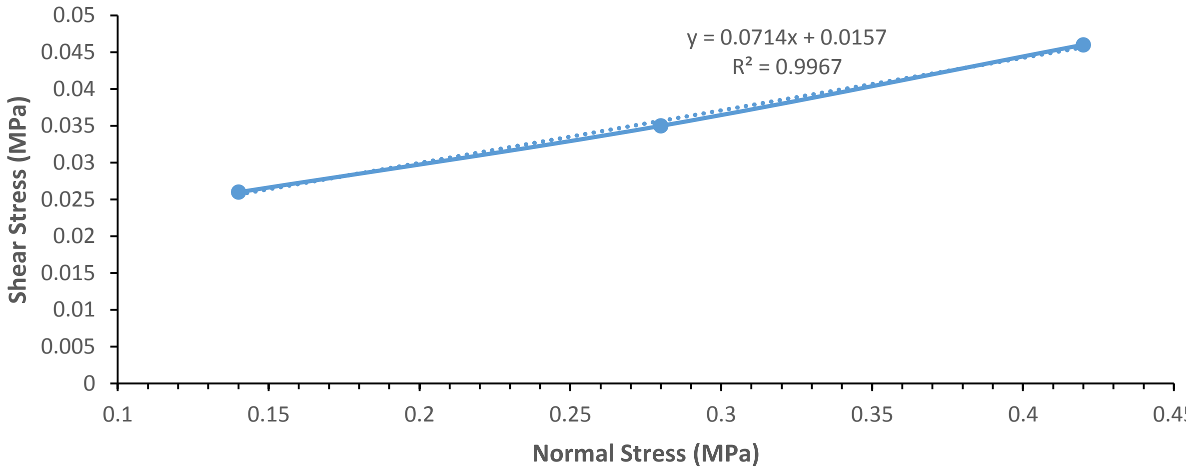

Figure 4.8 Shear Stress vs. Normal Stress for Fly Ash 97% + Lime 3% at 7 Days

From the above graph the X-intercept of the graph was found to be 0.0157, so the cohesive strength is 0.0157 Mpa. The slope of the graph was found to be 0.0714 which on further calculation gives friction angle $35^{0}48'$.

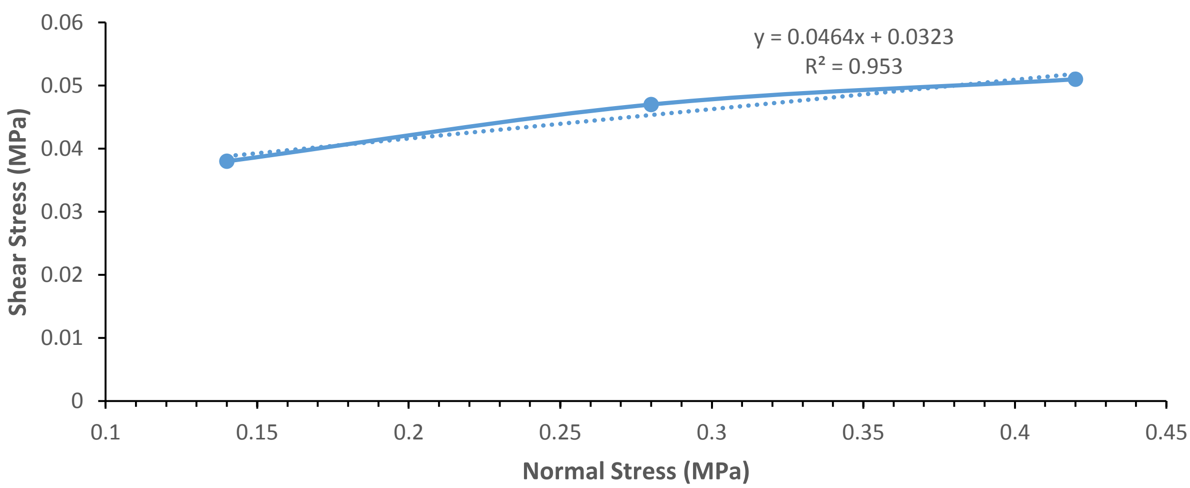

Figure 4.9 Shear Stress vs. Normal Stress for Fly Ash 95% + Lime 5% at 7 Days

From the above graph the X-intercept of the graph was found to be 0.0323, so the cohesive strength is 0.0323 Mpa. The slope of the graph was found to be 0.0464 which on further calculation gives friction angle $24^{0}00'$

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4.3.2 at 14 days

Table 4.5 Direct Shear Test Results at 14 Days

Combinations		**Dial Gauge reading**	**Failure reading**	**Shear Stress (MPa)**	**Normal Stress (MPa)**	**Cohesion (MPa)**	**Friction Angle**
FA(97)+ C(3)+ L(0)	0.5	100	13.0	0.032	0.14	0.0237	$30^{0}03'$
	1.0	180	19.0	0.039	0.28		
	1.5	60	18.0	0.048	0.42		
FA(95)+ C(5)+ L(0)	0.5	80	16.0	0.041	0.14	0.0297	$38^{0}24'$
	1.0	60	19.0	0.051	0.28		
	1.5	40	22.0	0.063	0.42		
FA(97)+ C(0)+ L(3)	0.5	80	12.0	0.031	0.14	0.0197	$39^{0}14'$
	1.0	60	16.0	0.043	0.28		
	1.5	80	21.0	0.054	0.42		
FA(95)+ C(0)+ L(5)	0.5	120	17.0	0.040	0.14	0.0277	$39^{0}14'$
	1.0	180	23.0	0.047	0.28		
	1.5	80	24.0	0.062	0.42		

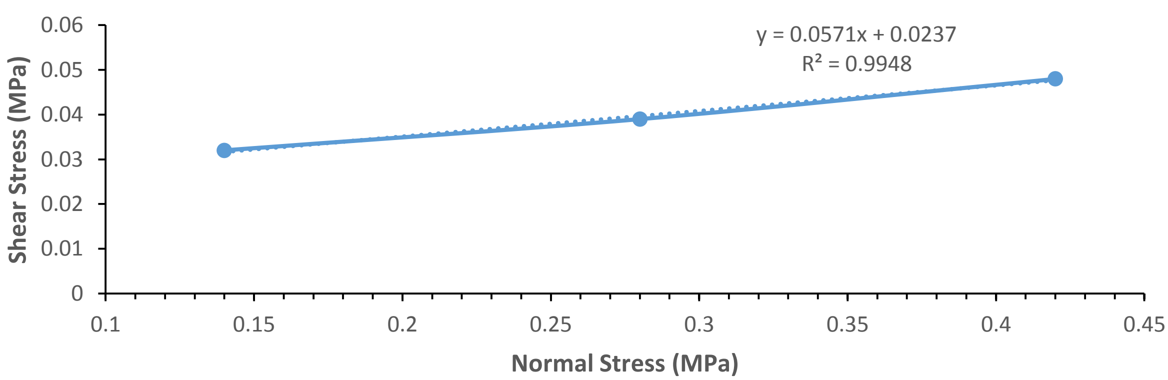

Figure 4.10 Shear Stress vs. Normal Stress for Fly Ash 97% + Cement 3% at 14 Days

From the above graph the X-intercept of the graph was found to be 0.0237, so the cohesive strength is 0.0237 Mpa. The slope of the graph was found to be 0.0571 which on further calculation gives friction angle $30^{0}03'$.

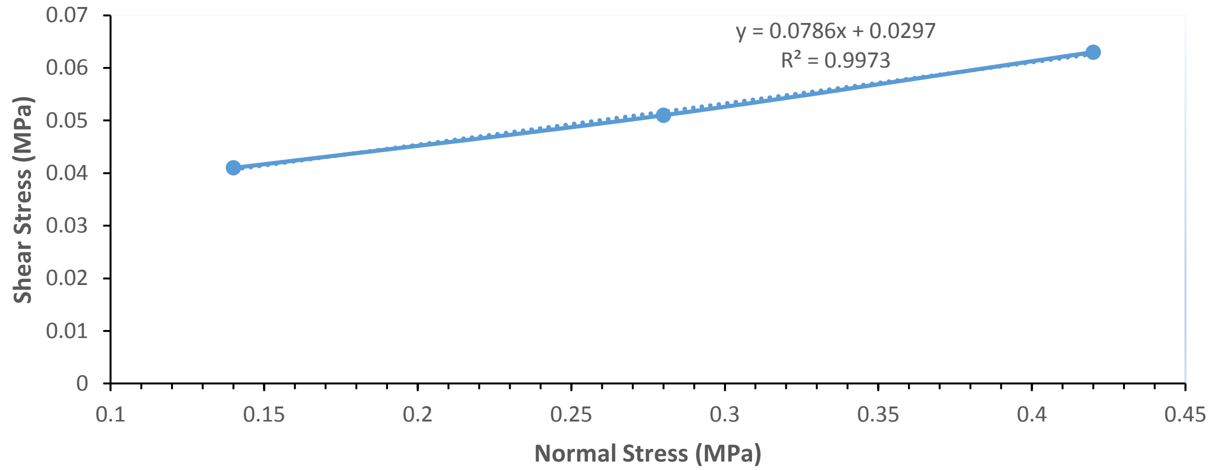

Figure 4.11 Shear Stress vs. Normal Stress for Fly Ash 95% + Cement 5% at 14 Days

From the above graph the X-intercept of the graph was found to be 0.0297, so the cohesive strength is 0.0297 Mpa. The slope of the graph was found to be 0.0786 which on further calculation gives friction angle $38^0 24'$.

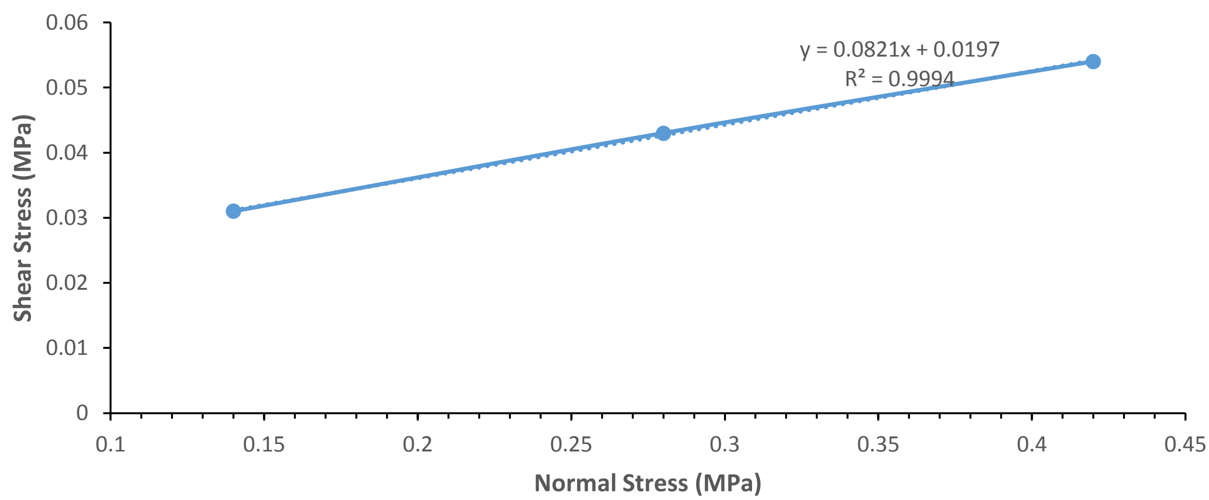

Figure 4.12 Shear Stress vs. Normal Stress for Fly Ash 97% + Lime 3% at 14 Days

From the above graph the X-intercept of the graph was found to be 0.0197, so the cohesive strength is 0.0197 Mpa. The slope of the graph was found to be 0.0821 which on further calculation gives friction angle $39^0 14'$.

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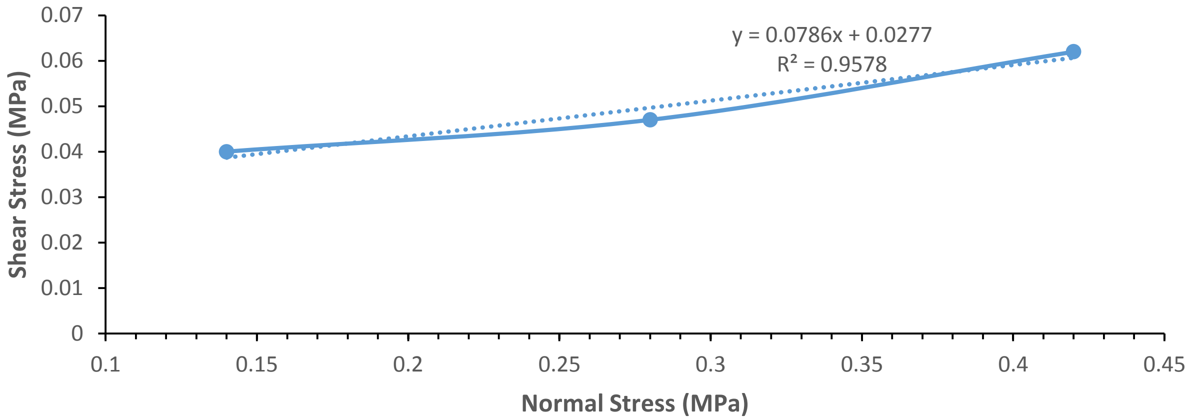

Figure 4.13 Shear Stress vs. Normal Stress for Fly Ash 95% + Lime 5% at 14 Days

From the above graph the X-intercept of the graph was found to be 0.0277, so the cohesive strength is 0.0277 Mpa. The slope of the graph was found to be 0.0786 which on further calculation gives friction angle $39^{0}14'$.

4.3.3 at 28 days

Table 4.6 Direct Shear Test Results at 28 Days

Combinations		Dial Gauge reading	Failure reading	Shear Stress (MPa)	Normal Stress (MPa)	Cohesion (MPa)	Friction Angle
FA(97)+ C(3)+ L(0)	0.5	60	16.0	0.043	0.14	0.0377	$21^{0}12'$
	1.0	80	19.0	0.049	0.28		
	1.5	100	22.0	0.054	0.42		
FA(95)+ C(5)+ L(0)	0.5	80	17.0	0.044	0.14	0.0330	$36^{0}25'$
	1.0	60	21.0	0.057	0.28		
	1.5	100	26.0	0.064	0.42		
FA(97)+ C(0)+ L(3)	0.5	80	15.0	0.039	0.14	0.0273	$41^{0}08'$
	1.0	60	20.0	0.054	0.28		
	1.5	100	26.0	0.064	0.42		
FA(95)+ C(0)+ L(5)	0.5	120	20.0	0.047	0.14	0.0333	$44^{0}47'$
	1.0	60	23.0	0.062	0.28		
	1.5	80	29.0	0.075	0.42		

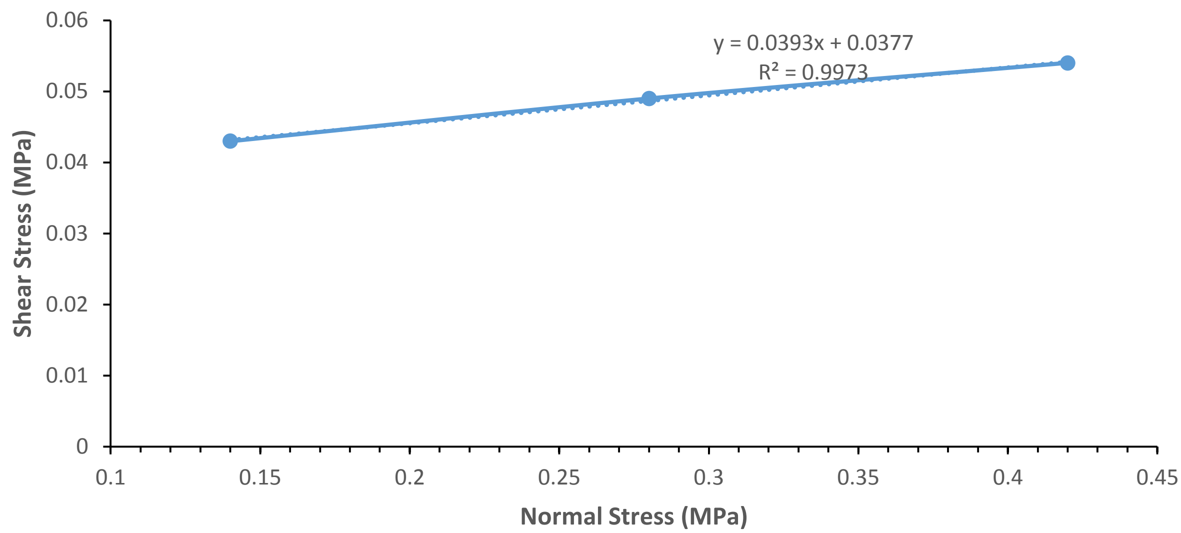

Figure 4.14 Shear Stress vs. Normal Stress for Fly Ash 97% + Cement 3% at 28 Days

From the above graph the X-intercept of the graph was found to be 0.0377, so the cohesive strength is 0.0377 Mpa. The slope of the graph was found to be 0.0393 which on further calculation gives friction angle $21^0$12'.

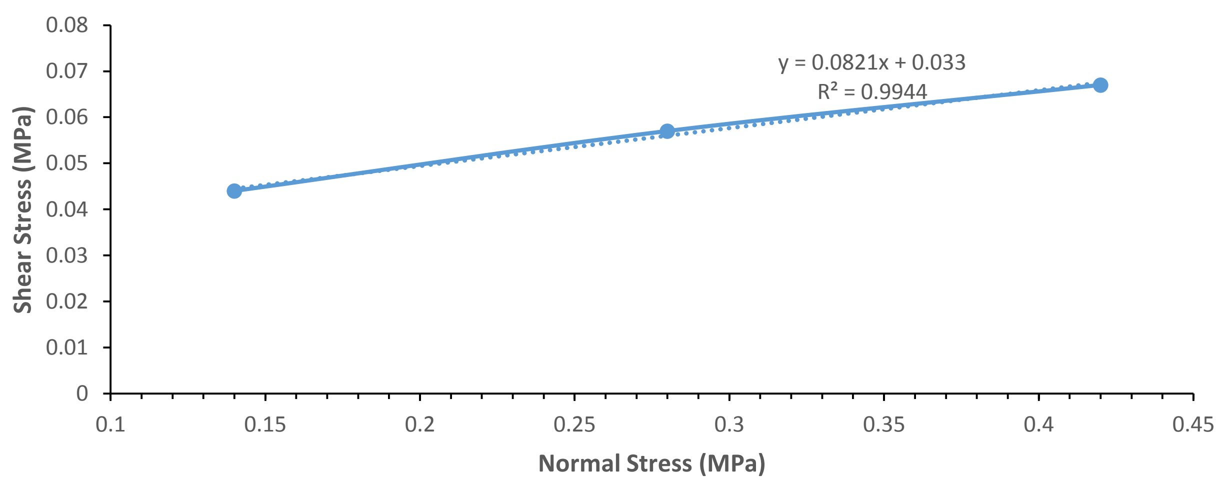

Figure 4.15 Shear Stress vs. Normal Stress for Fly Ash 95% + Cement 5% at 28 Days

From the above graph the X-intercept of the graph was found to be 0.033, so the cohesive strength is 0.033 Mpa. The slope of the graph was found to be 0.0821 which on further calculation gives friction angle $36^0$25'.

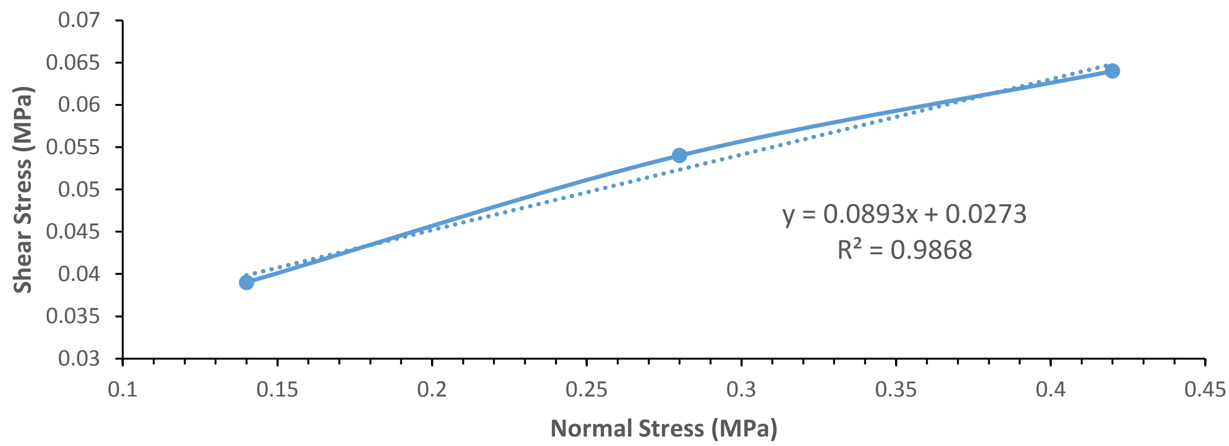

Figure 4.16 Shear Stress vs. Normal Stress for Fly Ash 97% + Lime 3% at 28 Days

From the above graph the X-intercept of the graph was found to be 0.0273, so the cohesive strength is 0.0273 Mpa. The slope of the graph was found to be 0.0321 which on further calculation gives friction angle $17^0 34'$.

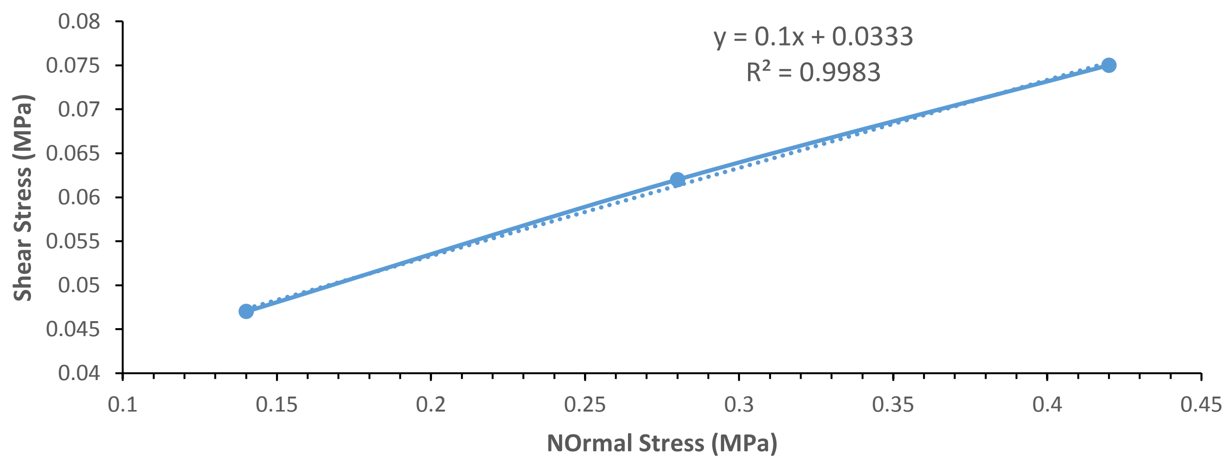

Figure 4.17 Shear Stress vs. Normal Stress for Fly Ash 95% + Lime 5% at 28 Days

From the above graph the X-intercept of the graph was found to be 0.0333, so the cohesive strength is 0.0333 Mpa. The slope of the graph was found to be 0.1 which on further calculation gives friction angle $44^0 47'$.

4.4 GRAPHICAL ANALYSIS

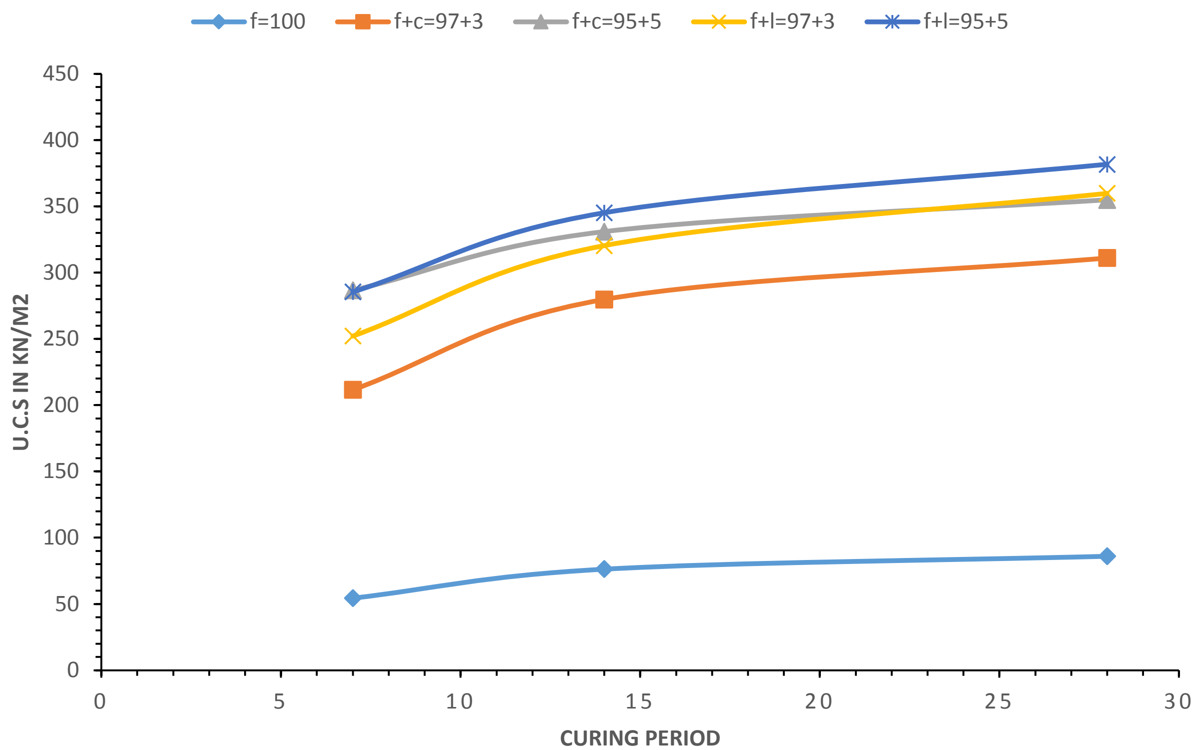

Figure 4.18 Curing Period vs. U.C.S for all the composites

It was found from the above graph that the strength of the Fly ash (100%) sample was around 54.4kN/m^2 for 7 days curing period which increases marginally at 14 days and 28 days. The U.C.S increases 3-4 times when 3% cement is added and 5-6 times when 5% cement is added for the same curing period. For curing period of 14 days it increases 3.5- 4.5 times and 5.5- 6.5 times for 3% & 5% cement respectively. For 28 days curing period it's marginally increases from 14 days.

Whereas in case of lime addition , for 7 days curing period it increases 3.5 – 4.5 times and 5.5 -6.5 times for 3% & 5% lime respectively. For curing period of 14 days it increases 4- 5 times and 6-7 times for 3% & 5% lime respectively. The increase in strength from 7 days to 14 days is greater than the increase from 14 days to 28 days for all the cases.

The composites having lime showed a better amount of strength than composites having cement because of higher concentration of CaO.

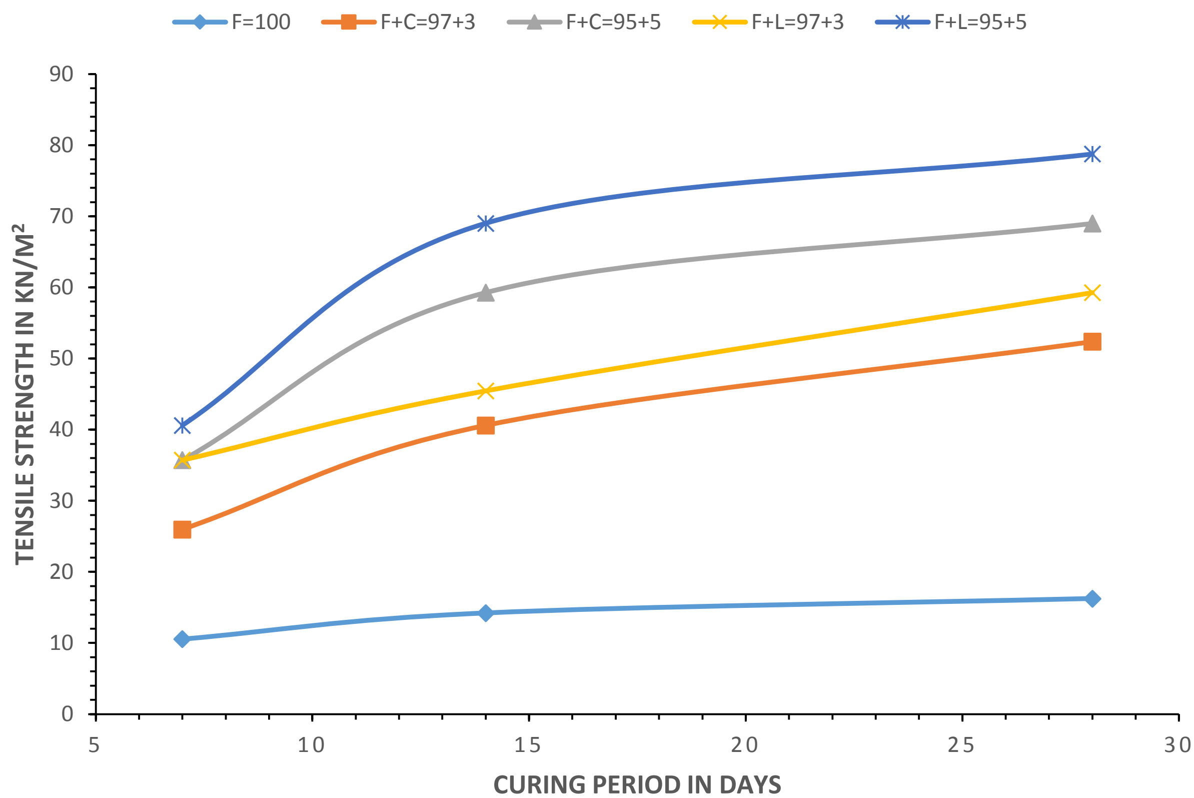

Figure 4.19 Curing Period vs. Tensile Strength for all the composites

It was found from the graph that the strength of the Fly ash (100%) sample was around 10.4kN/m^2 at 7 days curing period and it increases 3-4 times and 5-6 times for 3% & 5% cement respectively for the same curing period. for curing period of 14 days it increases drastically as were in case of U.C.S. (3.5- 4.5 times and 5.5- 6.5 times for 3% & 5% cement respectively). For 28 days curing period it's marginally increases from 14 days.

Whereas in case of lime addition , for 7 days curing period it increases 3.5 – 4.5 times and 5.5 -6.5 times for 3% & 5% lime respectively. For curing period of 14 days it increases drastically as were in case of UCS (4- 5 times and 6-7 times for 3% & 5% lime respectively). For 28 days curing period it's marginally increases from 14 days.

Here, also the composites having lime showed a better amount of strength than composites having cement because of higher concentration of CaO.

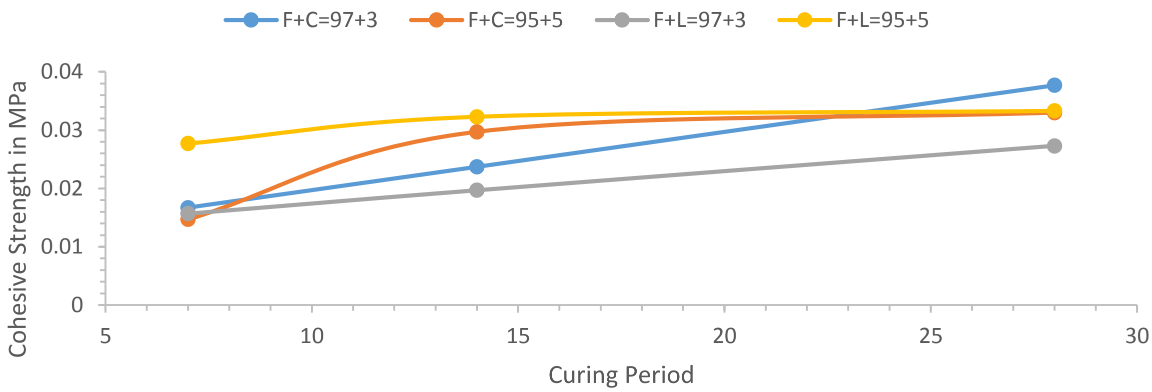

Figure 4.19 Curing Period vs. Cohesive Strength for all the composites

No shear test was done for Fly ash (100%) as the samples were not strong enough. Graph shows that cohesive strength increases as the percentage of cement & lime increases. At 7 days curing period for 3% & 5% cement it is almost same (0.015MPA). For 5% cement there is a drastically increment in it for 14 days curing period and then it increases marginally for 28 day curing period. For 3% cement, there is more or less a straight line.

Whereas in case of 3% lime it increases as were in case of 3% cement. For 5% lime it fist reduces (.035 to 0.025 MPA) for curing period of 7-14 days, and there is marginal increment for curing period of 14- 28 days.

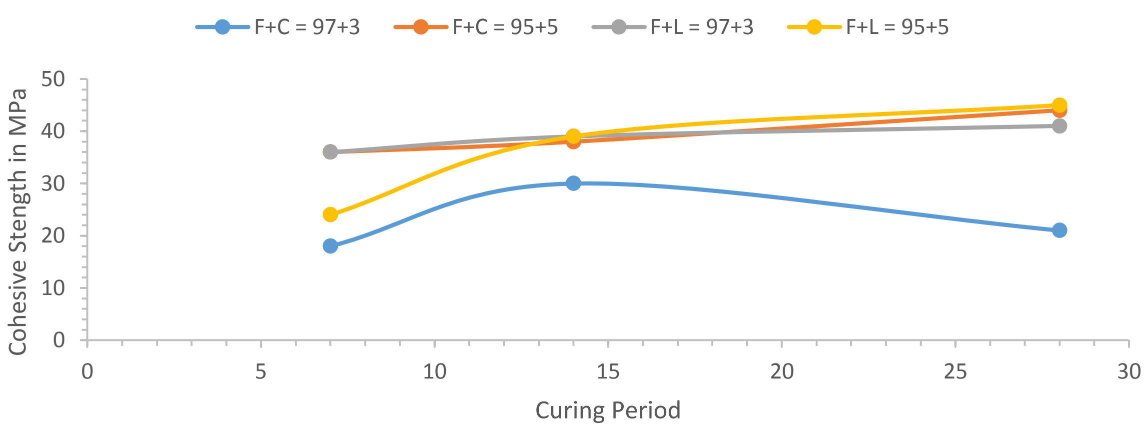

Figure 4.20 Curing Period vs. Friction Angle for all the composites

It was obtained from the graph that the frictional angle was changing at an irregular manner for the composites as lime and cement percentage were increasing. This happened because friction angle does not depend upon time. The friction angle was changing in a range of 15 to 45 degrees.

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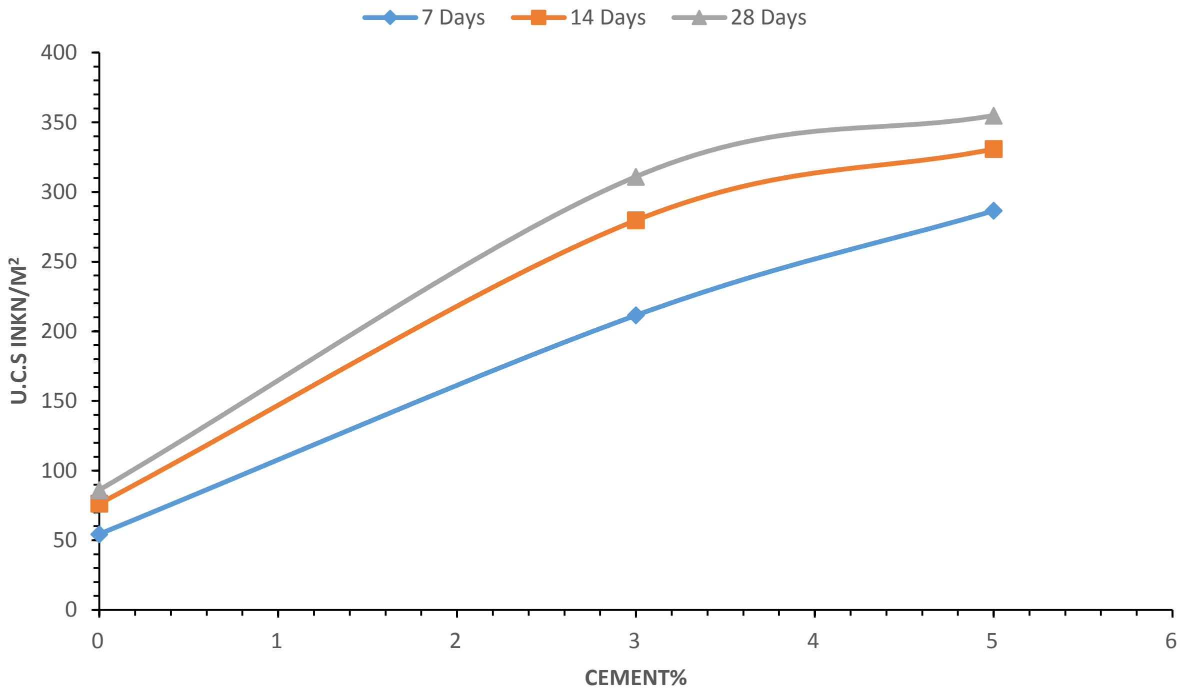

Figure 4.21 Cement % vs. U.C.S at Different Curing Periods

The above Graph shows that as the percentage of cement is increases, U.C.S increases. For curing period of 7 -14 days, there is a steep increment in it where as it marginally increases for 14- 28 days curing period. For 3% cement the strength is 150, 250, 300 KN/m2 for curing period of 7, 14, and 28 days respectively. Whereas in case of 5% cement it is 200, 300, 350 KN/m2 for curing period of 7, 14, and 28 days respectively. The increase in strength from 7 days to 14 days is greater than the increase from 14 days to 28 days for all the cases. After 7 days it more or less stabilizes and shows a lesser increase for all the composites.

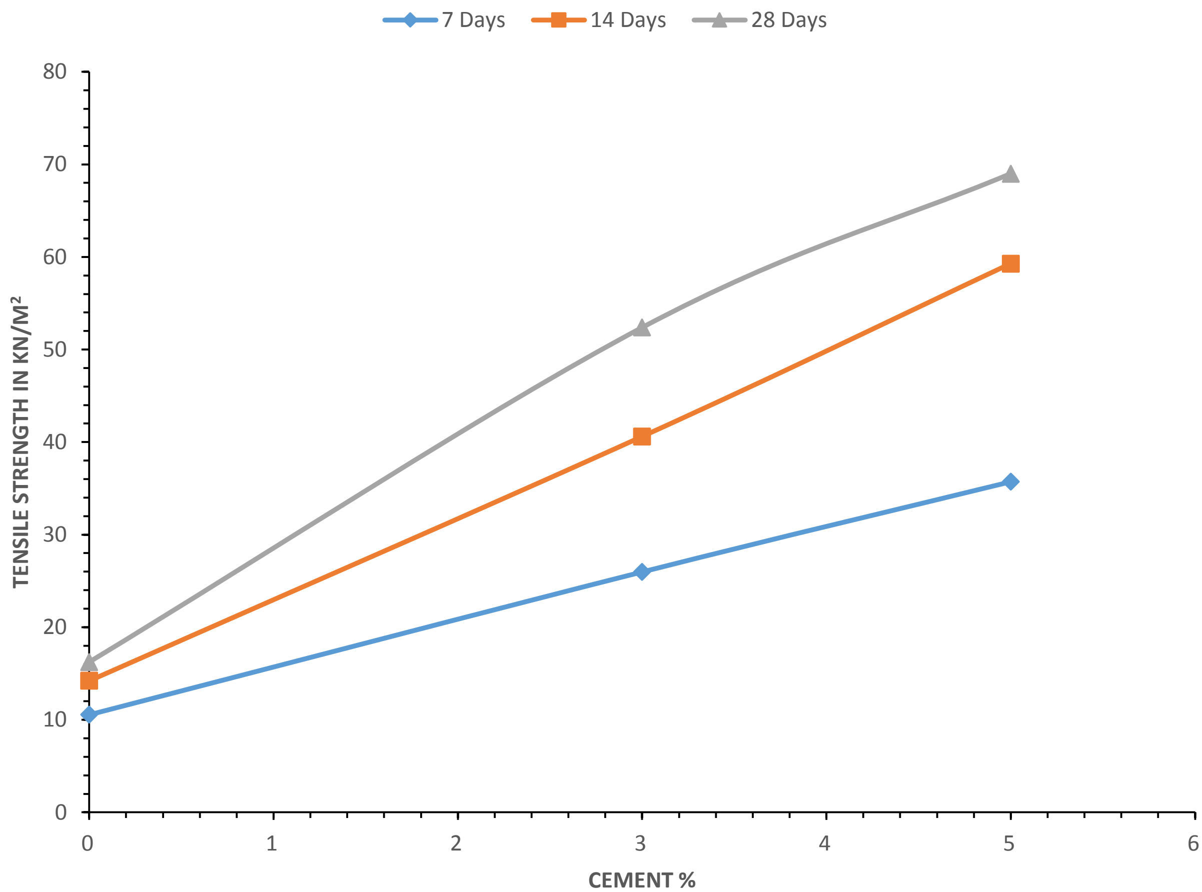

Figure 4.22 Cement % vs. Tensile Strength at Different Curing Periods

The above Graph shows that as the percentage of cement is increases, U.T.S increases and more is curing period more is the strength. For 3% the tensile strengths are 20, 35, 50 KN/m2 for curing period of 7, 14, and 28 days. Whereas in case of 5% cement it is 25, 50, 60 KN/m2 for curing period of 7, 14 and 28 days respectively. Here the curves are more of a straight line because tensile strengths have a lower value than U.C.S. The increase in tensile strength from 7 days to 14 days is greater than the increase from 14 days to 28 days for all the cases.

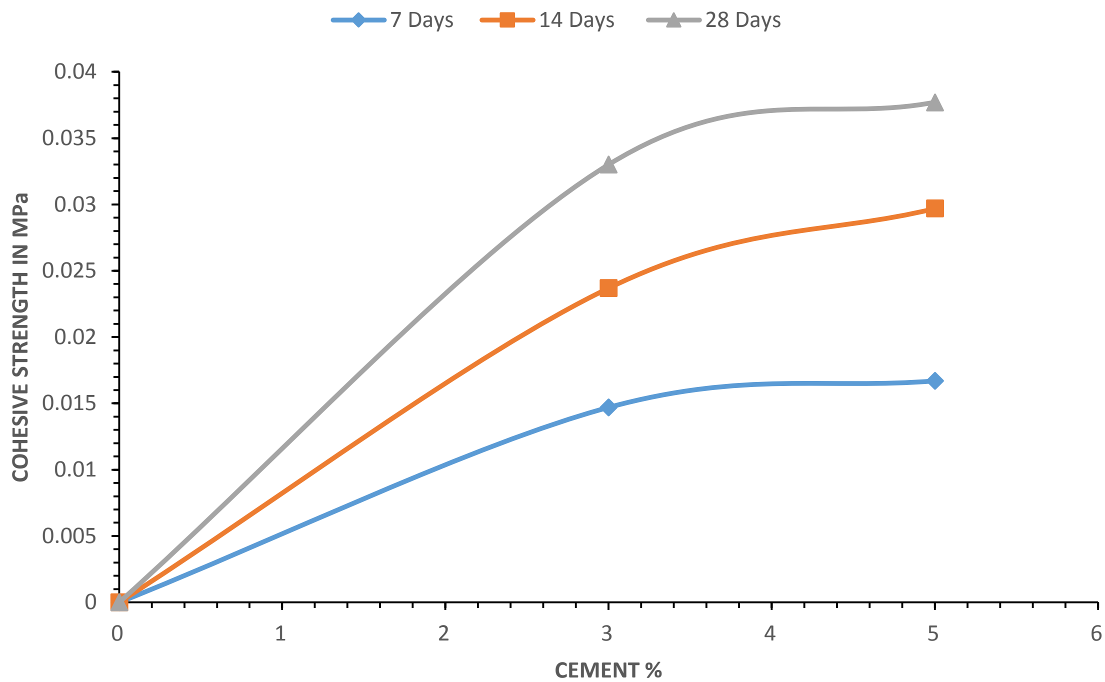

Figure 4.23 Cement % vs. Cohesive Strength at Different Curing Periods

The above graph shows that while adding 3% cement , there is a strip increase in the cohesive strength , it is 0.0147, 0.0237, 0.0.33 MPA for 7, 14 and 28 days curing period, respectively. Whereas in case of 5% cement addition, there is a marginal increase in cohesive strength and it is 0.0167, 0.0297, and 0.377 for 7, 14 and 28 days curing period respectively. The strength of composites having cement 0% have zero cohesive strength as these samples were not strong enough to conduct direct shear test on them.

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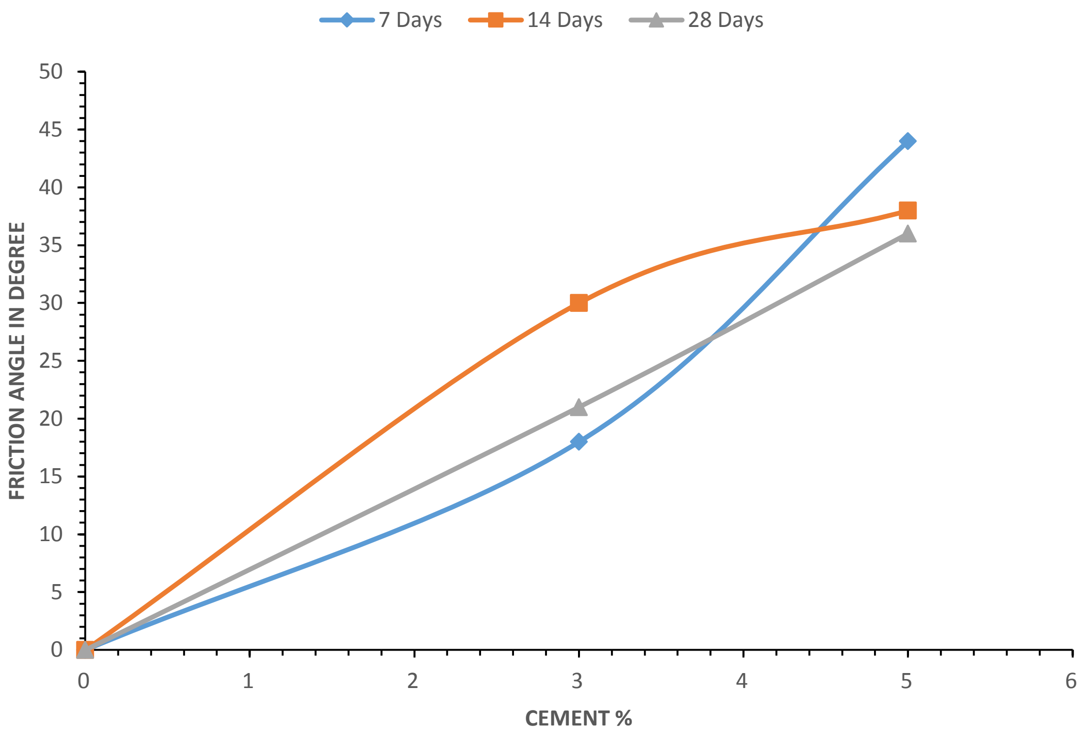

Figure 4.24 Cement % vs. Friction angle at Different Curing Periods

It was obtained from the graph that the frictional angle was changing at an irregular manner for the composites as cement percentage were increasing. For the composites having 3% cement, it is 18^0, 21^0, 30^0 at curing period of 7, 14 and 28 days respectively. Whereas, for the composites having 5% cement, it is 44^0, 36^0, 38^0 at the curing period of 7, 14 and 28 days respectively. For different composites different amount of increase was seen. The curves are different at different curing periods while at 28 days it tends to become a straight line.

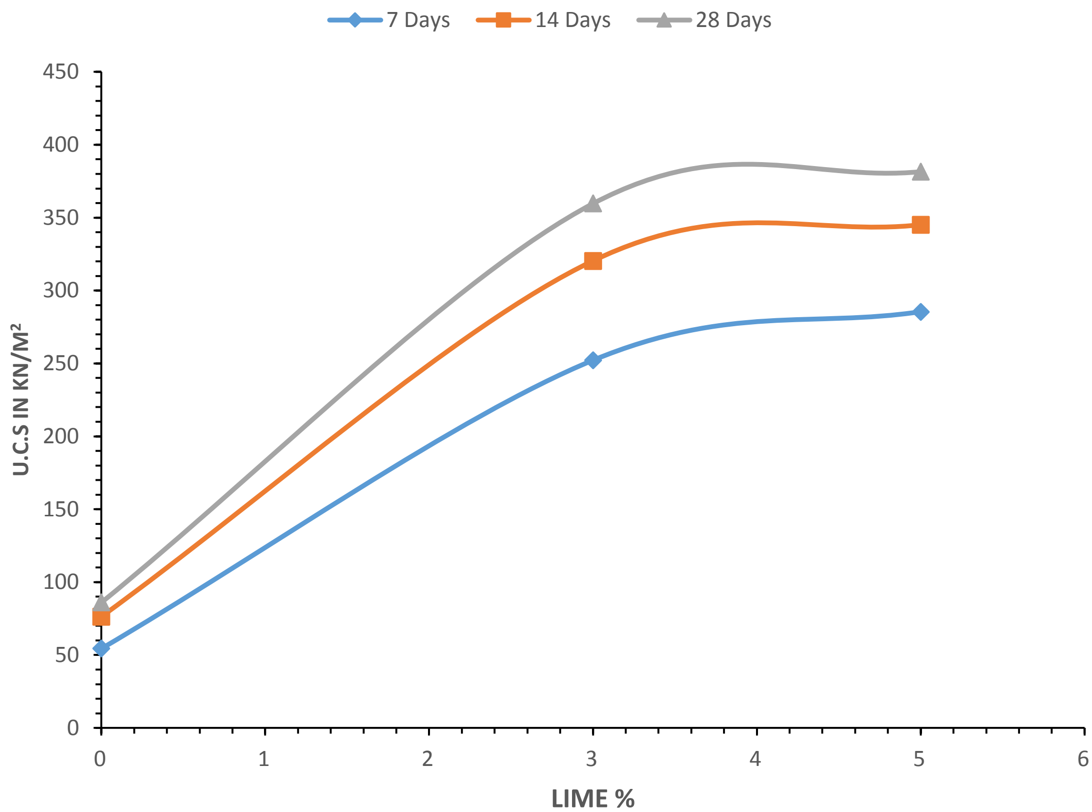

Figure 4.25 Lime % vs. U.C.S at Different Curing Periods

The above Graph shows that as the percentage of lime increases, U.C.S increases. For curing period of 7 -14 days, there is a steep increment in it where as it marginally increases for 14- 28 days curing period. For 3% lime the strength varies from 225-350 KN/m2 for curing period of 7, 14, and 28 days respectively. Whereas in case of 5% lime it varies from 250-375 KN/m2 for curing period of 7, 14, and 28 days respectively. The increase in strength from 7 days to 14 days is greater than the increase from 14 days to 28 days for all the cases. After 7 days it more or less stabilizes and shows a lesser increase for all the composites.

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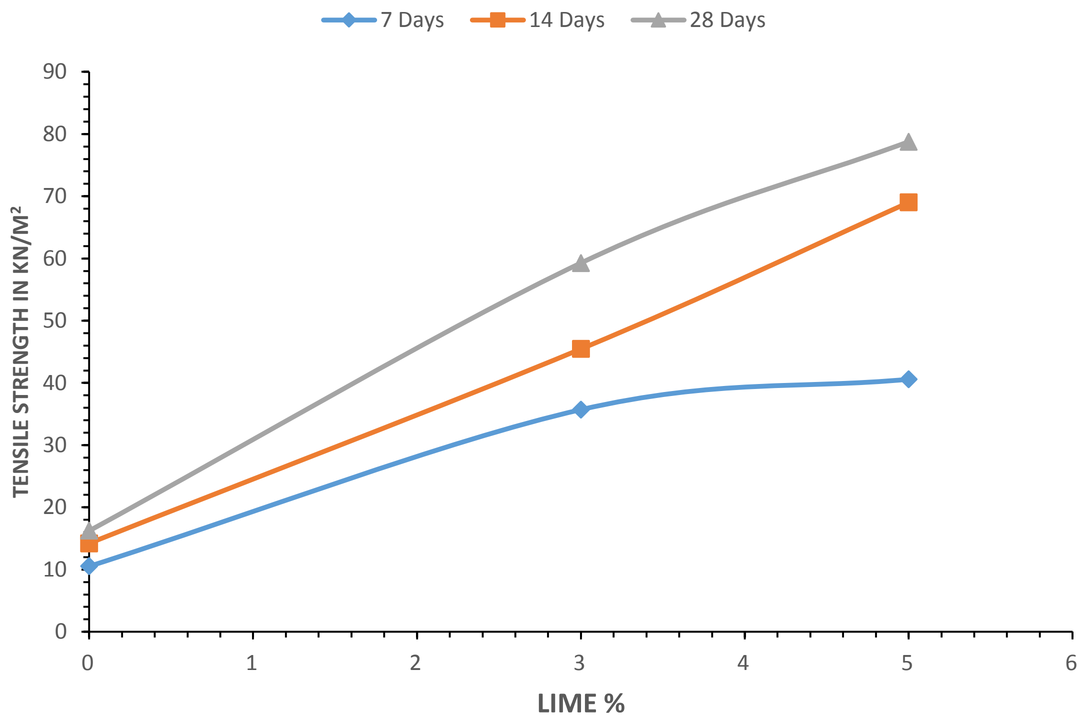

Figure 4.26 Lime % vs. Tensile Strength at Different Curing Periods

The above Graph shows that as the percentage of cement is increases, U.T.S increases and more is curing period more is the strength. For 3% lime the tensile strengths varies from 25-55KN/m2 for curing period of 7, 14, and 28 days. Whereas in case of 5% cement it varies from 30-75 KN/m2 for curing period of 7, 14 and 28 days respectively. Here the curves are more of a straight line because tensile strengths have a lower value than U.C.S. The increase in tensile strength from 7 days to 14 days is greater than the increase from 14 days to 28 days for all the cases.

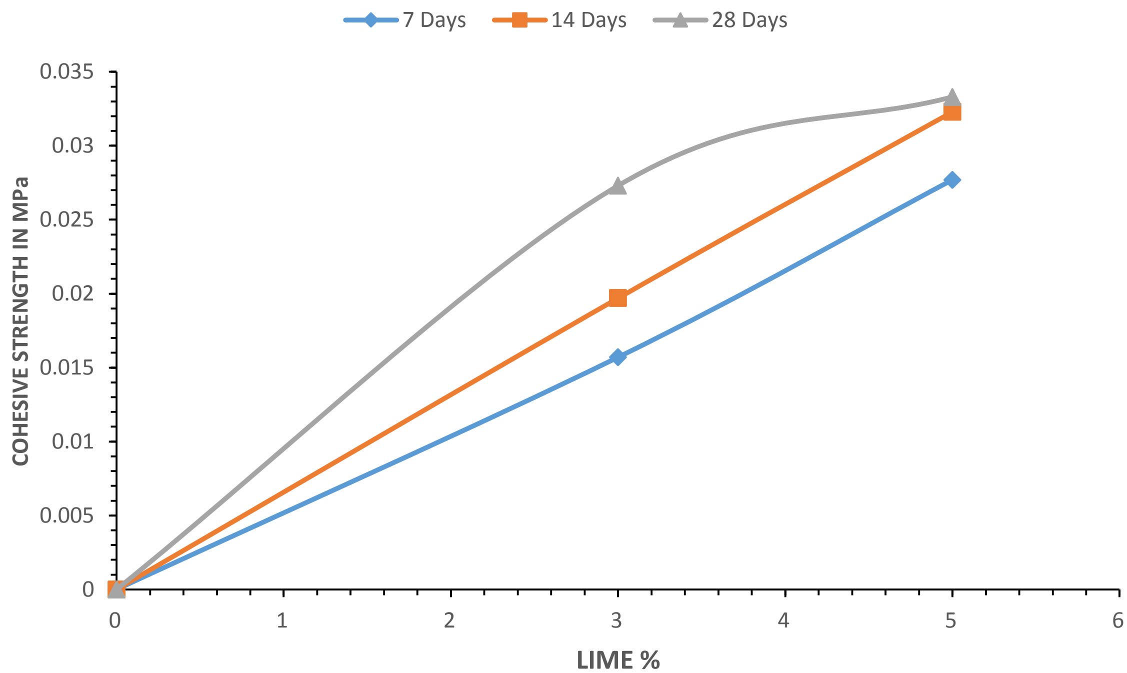

Figure 4.27 Lime % vs. Cohesive Strength at Different Curing Periods

The above graph shows that as the percentage of lime increases, cohesive strength of the composite also increases. And more is the curing period more is composite strength but in case of 5% lime it marginally increases for 14- 28 days curing period. For 3% lime it is 0.0157, 0.197, 0.0273 MPA at curing period of 7, 14 and 28 days, respectively. Whereas in case of 5% lime it is 0.0277, 0.0323, 0.0333 MPA at curing period of 7, 14 and 28 days respectively. The strength of composites having lime 0% have zero cohesive strength as these samples were not strong enough to conduct direct shear test on them.

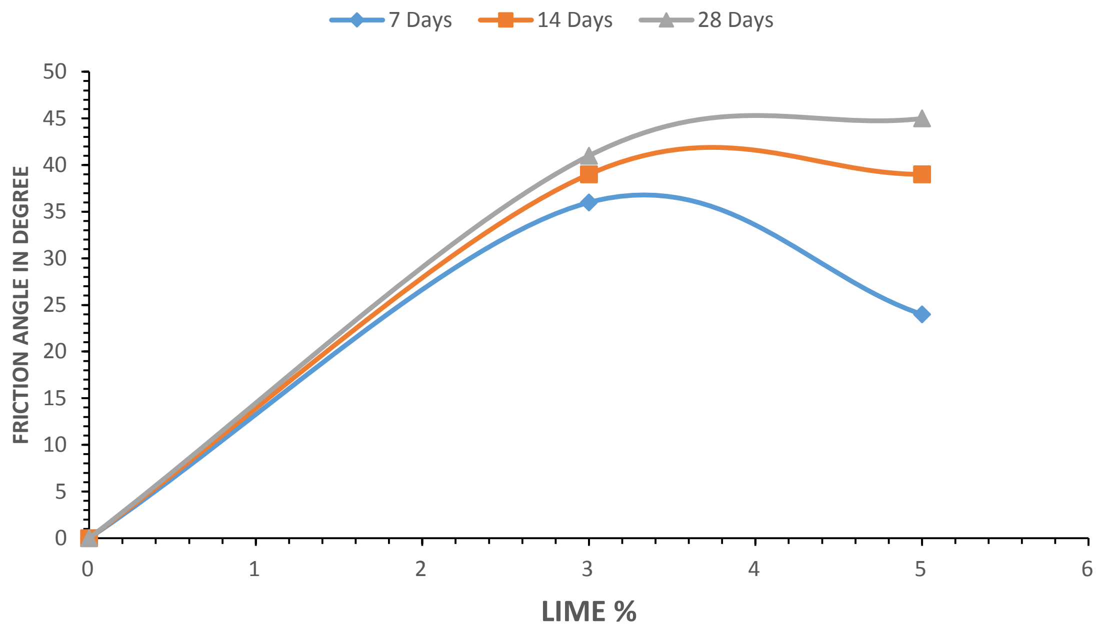

Figure 4.28 Lime % vs. Friction Angle at Different Curing Periods

The above graph shows that for 3% lime, there is an increment in friction angle but for 5% lime, it decreases. For 3% lime it is 36^0, 39^0, 41^0 at curing period of 7, 14 and 28 days respectively. Whereas in case of 5% lime content it is 24^0, 39^0, 45^0 at curing period of 7, 14 and 28 days respectively. For different composites different amount of increase was seen. The curves are different at different curing periods while at 28 days it tends to become a straight line. For all curing period the friction angle increases after 3% except in case of 7 days it decreases.

Analysis for Fly Ash % vs. U.C.S at Different Curing Periods

It was found from the above graph that the strength of the Fly ash (100%) sample was around 54.4kN/m^2 for 7 days curing period which increases marginally at 14 days and 28 days. As fly ash % decreases strength increases. The U.C.S increases 3-4 times when 3% cement is added and 5-6 times when 5% cement is added for the same curing period. For curing period of 14 days it increases 3.5- 4.5 times and 5.5- 6.5 times for 3% & 5% cement respectively. For 28 days curing period it's marginally increases from 14 days.

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Whereas in case of lime addition , for 7 days curing period it increases 3.5 – 4.5 times and 5.5 -6.5 times for 3% & 5% lime respectively. For curing period of 14 days it increases 4- 5 times and 6-7 times for 3% & 5% lime respectively. The increase in strength from 7 days to 14 days is greater than the increase from 14 days to 28 days for all the cases.

The composites having lime showed a better amount of strength than composites having cement because of higher concentration of CaO.

Analysis for Fly Ash % vs. Tensile Strength at Different Curing Periods

It was found from the graph that the strength of the Fly ash (100%) sample was around 10.4kN/m^2. As fly ash % decreases strength increases. At 7 days curing period and it increases 3-4 times and 5-6 times for 3% & 5% cement respectively for the same curing period. For curing period of 14 days it increases drastically as were in case of U.C.S. (3.5- 4.5 times and 5.5- 6.5 times for 3% & 5% cement respectively). For 28 days curing period it's marginally increases from 14 days.

Whereas in case of lime addition , for 7 days curing period it increases 3.5 – 4.5 times and 5.5 -6.5 times for 3% & 5% lime respectively. For curing period of 14 days it increases drastically as were in case of UCS (4- 5 times and 6-7 times for 3% & 5% lime respectively). For 28 days curing period it's marginally increases from 14 days.

Here, also the composites having lime showed a better amount of strength than composites having cement because of higher concentration of CaO.

Analysis for Fly Ash % vs. Cohesive Strength at Different Curing Periods

No shear test was done for Fly ash (100%) as the samples were not strong enough. Graph shows that cohesive strength increases as the percentage of cement & lime increases. At 7 days curing period for 3% & 5% cement it is almost same (0.015MPA). For 5% cement there is a drastically increment in it for 14 days curing period and then it increases marginally for 28 day curing period. For 3% cement, there is more or less a straight line.

Whereas in case of 3% lime it increases as were in case of 3% cement. For 5% lime it fist reduces (.035 to 0.025 MPA) for curing period of 7-14 days, and there is marginal increment for curing period of 14- 28 days.

Analysis for Fly Ash % vs. Friction angle at Different Curing Periods

It was obtained from the graph that the frictional angle was changing at an irregular manner for the composites as lime and cement percentage were increasing. This happened because friction angle does not depend upon time. The friction angle was changing in a range of 15 to 45 degrees.

It was obtained from the graph that the frictional angle was changing at an irregular manner for the composites as cement percentage were increasing.

For the composites having 3% cement, it is 18^0, 21^0, 30^0 at curing period of 7, 14 and 28 days respectively. Whereas, for the composites having 5% cement, it is 44^0, 36^0, 38^0 at the curing period of 7, 14 and 28 days respectively. For different composites different amount of increase was seen. The curves are different at different curing periods while at 28 days it tends to become a straight line.

4.5 DISCUSSION

Compressive strength test provides the resistance of the composites to external loading. UCS tests were conducted on fly ash composite {Fly Ash (100%), Fly Ash + Cement (97%+3%), Fly Ash + Cement (95%+5%), Fly Ash + Lime (97%+3%), Fly Ash + Lime (95%+5%)} for 7 days, 14 days and 28 days curing period at room temperature that was about 25^0C and humidity of 90%.

The strength of 7 days cured samples of raw fly ash are very low with only 54.4 KN/m^2 and a very marginal increase for 14 and 28 days cured samples. The strength increases by 4 times by adding 3% cement and keeps on increasing for 3 % lime for 7 days curing. The strength increases by 5-6 times by adding 5% cement and keeps on increasing for 5% lime for 7 days curing. For composites having cement and lime the increase in strength is about 30%-40% between 7 days to 14 days curing period while this increase comes down to 10%-20% between 14 days to 28 days curing period. For every sample the strength increment is more from 7 days to 14 days curing period and less for 14 days to 28 days curing period.

Tensile strength test provides resistance of the composites to external tensile forces. Brazilian indirect tensile strength tests were carried out to determine the tensile strength of the fly ash composites in the same testing machine used to find the compressive strength. The samples for the test measured 56 mm in diameter and 28 mm in thickness were cut from the specimen prepared for compressive strength tests. The samples were loaded along the diametrical axis as mentioned in the method. The increase in strength from 0% to 3% limes content is 2-3 times whereas from 0 % to 5 % lime it is 3-4 times. The increase in strength from 0% to 3% cement content is 1.5-2.5 times whereas from 0 % to 5 % cement it is 2.5-3.5 times. For every sample the strength increment is more from 7 days to 14 days curing period and less for 14 days to 28 days curing period.

The **Direct shear test** provided the values of cohesive force and friction angle from the graph plotted between shear stress and normal stress resulted from the test. No shear test was done for Fly ash (100%) as the samples were not strong enough. It was observed that the cohesive force increases as lime or cement % increases but it was more in case of lime. The frictional angle was changing at a lower rate for the composites as lime and cement percentage were increasing.

Chapter 5

CONCLUSION

5.1 CONCLUSION

The aim of the present investigation was to develop a better suited combination of fly ash composite materials to use it as an alternative to sand as a backfilling material to increase its utilization percentage. The fly ash composites developed with the addition of lime and cement were found to have increased strength characteristic than only fly-ash.

The following conclusions were drawn from the investigation conducted.

1. The fly ash of local power plant without any addition of lime or cement possessed negligible U.C.S which is 54.40KN/m^2 at 7 days which marginally increases at 14 days and 28 days.
2. With 3% addition of cement the U.C.S value increased up to 4-5 times and with 5% the value increases up to 5-6 times.
3. Similarly with 3% addition of lime the U.C.S value increased up to 5-6 times and with 5% the value increases up to 6-7 times.
4. So lime provided better strength as it have more Cao.
5. There was a steep increased in Curating Period vs. U.C.S graph.
6. The tensile strength of the fly ash sample was very negligible with only 10.55 KN/m^2
7. With 3% addition of cement the tensile strength value increased up to 2-3 times and with 5% the value increased up to 3-4 times.
8. Similarly with 3% addition of lime the U.C.S value increased up to 3-4 times and with 5% the value increased up to 4-5 times.
9. There was a low rate of increase in Curating Period vs. Tensile Strength graph.
10. No shear test could be done for Fly Ash (100 %) samples as they did not have enough strength for direct shear test.
11. The direct shear test showed a gradual increase in the cohesive strength as % of cement and lime increases but in a less regulated manner.
12. Fly ash-lime composite exhibits best characteristic as compare to cement.
13. Fly as with 5% lime exhibited the maximum strength value at all curing period.

The major conclusion of the study was that the fly ash from RSP has greater potential to be developed into a strong engineering material with the addition of lime, and cement.

5.2 FUTURE SCOPE

The current investigation was limited to laboratory analysis. It is recommended to check the following for a better suited combination for fly ash composites.

1. Fly ash composites with greater percentage of lime and cement (more than 5) should be examined to evaluate their geo-technical properties.
2. Long term effects of fly ash composite should be evaluated in actual field condition.
3. More curing period should be provided to find more results.
4. Numerical investigations can be carried out by modelling to predict strength of fly ash composites.

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